Preparation of Oil Palm Frond (OPF) for biomass Gasification

by

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Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

OCTOBER 2010

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Universiti Teknologi PETRONAS
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BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

(Ir. Dr. Shaharin Anwar Bin Sulaiman)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
August 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Mohammad Syafiq B Samsudin

ABSTRACT

Due to the abundance source of unutilized OPF in Malaysia, the usage of OPF as the fuel for biomass gasification seems to be a very attractive solution. However, because of the natural properties of OPF and the requirement of the gasifiers, there are certain process that should be apply to prepare OPF before it is safe to be feed into any gasifiers. The problems like the a very low efficiency system, corrosion of the flue, high emission of tars and creosote that condense in the flue, and flue blockages could be avoid or decrease by preparing OPF into a suitable size and by eliminating its moisture content until below 20% (although some of the gasifiers only require less than 55% to 60% moisture content). OPF drying process is also essential for storing purpose as it could reduce the risk of losing its energy value. The objectives of this project is to analyz OPF properties and to experiment methods in preparing OPF for biomass gasification in order to provide fundamental suggestion in using OPF for biomass gasification for industrial purpose. Starting with data collection and fundamental studies, OPF, the projects covering experiments, collection of data and analyzing results in cutting, drying and storage process of OPF for biomass gasification, whereby in drying, basically there are two methods covered which are sun drying and furnace drying. It is found out that with the right method in cutting/preparing of OPF especially if it include the process of crushing and fine cutting, sun drying method should be enough to dried out the moisture content in OPF until it reach the level of below 10%. Sun drying process could take only one day period for a whole day in sunny weather, or it could take 2 days if it is cloudy or sometimes 3 days if it is often raining during the day. On the other hand, furnace drying is not practical to be used widely for industrial basically because it consume high amount of energy and it is believe to be very costly. Dried OPF feedstock (moisture content below 10%) could be store and preserve in room condition for a long period of time without any major change in its value.

ACKNOWLEDGEMENT

I would like to take this opportunity to firstly thank my supervisor, Ir. Dr. Shaharin Anwar Bin Sulaiman, who has guided me through this project. I would also like to thank the panel of examiners, Prof. Vijay R. Raghavan for their important feedbacks. Besides that, thank you too to other UTP staff and UTP post-graduates for their guidance, support, advices and assistance in technically or morally. Special thanks also to the 'FELCRA Hj Nasarudin, Bota staffs, especially Mr. Fadli for his corporation in providing some of the requiring data about Oil Palm plantation. Finally, thank you to everyone else who have helped me in completing this project whether directly or indirectly.

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ABBREVIATIONS AND NOMENCLATURES

MC	Moisture Content
OPF	Oil Palm Frond
FELCRA	Federal Land Consolidation and Rehabilitation Authority

CHAPTER 1
INTRODUCTION

1.1 Project background

With recent price rise of petroleum fuel there has been a trend towards use of alternative energy sources like solar, wind, geothermal and etc. However these energy resources have not been able to provide an economically viable solution for agricultural applications. One biomass energy based system, which has been proven reliable and had been extensively used for transportation and on farm systems during World War II is biomass gasification. As prices for biomass fuels increase, it is especially important to use them efficiently.

There is a problem that solid wastes like Oil Palm Fronds (OPF) are seldom in a form that can be readily utilized economically which almost all pruned fronds are discarded in the plantation, mainly for nutrient recycling and soil conservation but the energy recovery is low. As a result it is often advantageous to convert this waste into more readily usable fuel. Hence the attractiveness of gasification process is it can turn many organic wastes into a much more commercially valuable form which is sync gas. However under present conditions, economic factors seem to provide the strongest argument of considering gasification. In many situations where the price of petroleum fuels is high or where supplies are unreliable the biomass gasification can provide an economically viable system. OPF is one of the most abundant agricultural by-products in Malaysia that have high potential but it still not being utilized properly. Therefore, it is believed that OPF could provide the suitable biomass feedstock that is easily available for biomass gasification. Gasification produces syngas (H_2 and CO) by heating biomass particles at temperature between 800°C and 1000°C. In gasification, biomass drying increases efficiency, improves operation, and can increase heat generation by up to 60%.

Oil palm fronds that are dried directly in the open air without sufficient heat application, it would be dried out in one month, degraded and turned into bright brown colour. In order to increase the efficiency of gasification by reducing the feedstock moisture content, OPF needs to be treated via drying process (conventional or advance treatment). By successfully reducing the moisture content of OPF, it simultaneously reducing the weight of OPF therefore the transportation process would be easier. Furthermore, the reduce amount of moisture content in OPF should decrease or prevent the risk of enzyme activity and growth of microorganisms that could reduce the OPF energy value, therefore drying could reduce the overall cost (reduce risk of losing feedstock due to deterioration).

Natural drying of OPF using the sun heat could be slow depending on the method of drying (feedstock condition and drying environment condition). The process could also expose OPF to the other problems. The risks are spoilage both during process and subsequent storage, insect and microbial infestation, and dust accumulation. All of these factors contribute to the final product quality.

In combustion systems any water content in the fuel must be driven off before the first stage of combustion can occur, requiring energy, and thus reducing overall system efficiency and potentially reducing combustion temperature below the optimum. Reduction in combustion temperature below the optimum may result in incomplete combustion of the fuel giving rise to the emission of tars and creosote which may condense in the flue, especially if it is long or includes changes of direction, and particulates. The water may also recondense in the flue, and all these may lead to corrosion of the flue and the gradual accretion of material leading to the potential for eventual blockages or fire. Even maintaining a flame in a boiler can be difficult if the fuel is too wet. Gasifiers, too, cannot tolerate high moisture contents. Some types of gasifiers require less than 55% to 60% moisture content and other require less than 20% moisture content for operation.

1.2 Problem Statement

Problems encountered in gasification of OPF are related to the properties of the fuel. The low energy density and high moisture content of biomass feedstock can affect the hydrogen production rate during the gasification.

To reduce the drying time, the oil palm fronds must be grounded to the smaller sizes. However, if the wet ground fronds are exposed to the atmosphere, it could degrade in unwanted manners within a day due to fungal attack and turns brown to black in colour and later a foul odour is emitted. It is therefore essentially that drying of the ground fronds is done quickly in the field.

In preparing OPF feedstock, it is essential to cut the frond before it is being too dry because dried fronds are usually brittle and shatter easily (especially when the moisture content is already below 10%).

High moisture content biomass has a much lower net energy density by mass, owing to the weight of the water, but also by volume owing to the energy required to evaporate the water. This means that transport is less efficient as a significant proportion of the load is water. Storage is also less efficient, with less net energy available, but also storage of high moisture content biomass brings other problems with greater risk of composting, causing loss of biomass and potentially a fire risk from elevated temperatures and mould formation. Good ventilation and air flow help to minimise these problems.

To maximize the OPF sync gas production, the OPF must be reduced to fine powder to perform gasification at high temperature. However, for the gassifier without blower, feedstock in powder form is ineffective because there will be not enough air or oxygen trap between the powder, that mean instead of it should burn easier, it will be harder because the whole powder will react as a big particle. Inconsistent size of feedstock could lead to formation of tar that cause choking and blockage in the gasifier due to the thermal instability of OPF. It also has been acknowledged that manual grinding OPF require a lot of energy and time consuming.

1.3 Objectives

The objective of this research project is to experiment and study the practical method in preparing OPF in order to produce a cheaper and more efficient biomass fuel from biomass gasification using OPF as the feedstock. The method should be practical enough for the Oil Palm farmers to implement it towards their disposing OPF therefore increase their estate productivity. The study focus on investigating the properties of oil palm fronds and comparing the effects and practicality of using different methods in preparing OPF in its cutting, drying and storing for biomass gasification

1.4 Scope of Study

In this project, the focus is to acquire details about OPF properties whether in biologically, chemically or mechanically. The OPF properties influence the choice of cutting tools to use in preparing OPF for drying process and the method to use for drying process. Other than that, the project is also focus on acquiring the data about OPF in industrial production which the data is essential to predict the practicality of using OPF for biomass gasification on the industrial level. While the project runs by experimenting on cutting, drying and storage method for OPF, in the end the best method in preparing OPF for biomass gasification is recommended by processing the data gain from the experiments such as the moisture content, time taken, total energy and cost estimation. The project is consider successful when it provides the key data and suggestions of the most efficient and practical method in preparing OPF for Biomass Gasification and could be used as a reference especially for industrial purpose.

CHAPTER 2
LITERATURE REVIEW

2.1 Biomass

According to Biomass Energy Centre Organization, UK, Biomass is biological material derived from living, or recently living organisms. In the context of biomass for energy this is often used to mean plant based material, but biomass can equally apply to both animal and vegetable derived material. Biomass is carbon based and is composed of a mixture of organic molecules containing hydrogen, usually including atoms of oxygen, often nitrogen and also small quantities of other atoms, including alkali, alkaline earth and heavy metals. These metals are often found in functional molecules such as the porphyrins which include chlorophyll which contains magnesium. For Plant Material, The carbon used to construct biomass is absorbed from the atmosphere as carbon dioxide (CO2) by plant life, using energy from the sun. Plants may subsequently be eaten by animals and thus converted into animal biomass. However the primary absorption is performed by plants. If plant material is not eaten it is generally either broken down by microrganisms or burned where if it is broken down it releases the carbon back to the atmosphere, mainly as either carbon dioxide (CO2) or methane (CH4), depending upon the conditions and processes involved and If it is burned the carbon is returned to the atmosphere as CO2. These processes have happened for as long as there have been plants on Earth and is part of what is known as the carbon cycle. There are a number of technological options available to make use of a wide variety of biomass types as a renewable energy source. Conversion technologies may release the energy directly, in the form of heat or electricity, or may convert it to another form, such as liquid biofuel or combustible biogas.

2.2 Biomass Gassification Process

Gasification is the controlled partial oxidation of a carbonaceous material, and it is achieved by supplying less oxygen than the stoichiometric requirement for complete combustion (Sadaka, 2008). During gasification process carbonaceous materials, such as biomass or coal, react with steam or a limited amount of air or oxygen producing a gaseous fuel. The products of gasification are mainly carbon monoxide and hydrogen with minor amount of carbon dioxide methane and other hydrocarbons. Biomass gasification means incomplete combustion of biomass resulting in production of combustible gases consisting of Carbon monoxide (CO), Hydrogen (H2) and traces of Methane (CH4). This mixture is called producer gas.

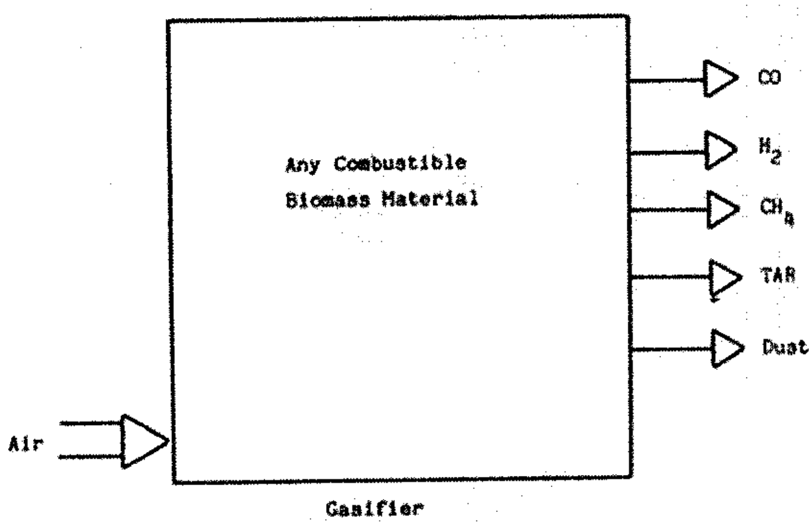


Figure 2.1: Product of Gasification

Producer gas can be used to run internal combustion engines (both compression and spark ignition), can be used as substitute for furnace oil in direct heat applications and can be used to produce, in an economically viable way (Rajvanshi 1986). On the other hand, methanol is an extremely attractive chemical which is useful both as fuel for heat engines as well as chemical feedstock for industries. Since any biomass material can undergo gasification, this process is much more attractive than ethanol production or biogas where only selected biomass materials can produce the fuel.

The history of gasification process was developed in the 1800s to produce town gas for lighting and cooking. Wood gasifiers, called Gasogene or Gazogène, were used to power motor vehicles in Europe during WWII fuel shortages. Other than that, the process of gasification to produce combustible from organic feeds was used in blast furnaces over 180 years ago. The possibility of using this gas for heating and power generation was soon realized and there emerged in Europe producer gas systems, which used charcoal and peat as feed material. At the turn of the century petroleum gained wider use as a fuel, but during both world wars and particularly World War II, shortage in petroleum supplies led to widespread re-introduction of gasification. By 1945 the gas was being used to power trucks, buses and agricultural and industrial machines. It is estimated that there were close to 9million vehicles running on producer gas all over the world.

2.3 Oil Palm Frond

Oil palm frond (OPF) is one of the most abundant, unutilized agricultural by-products in Malaysia. Almost all pruned fronds are discarded in the plantation, mainly for nutrient recycling and soil conservation (Wan Zahari, 2001). OPF has great potential for use as a roughage source or as a component in compound feed for ruminants. Much research has been carried out by MARDI and JIRCAS on use of OPF for animal feeding, either fresh, or processed as silage or pellet (Abu Hassan, Ishida and Mohd Sukri, 1995). Detailed studies on the fermentation characteristics and palatability of OPF silage, as well as on animal performance, have been reported (e.g. Abu Hassan and Ishida, 1991; Ishida and Abu Hassan, 1997; Oshio et al., 1999). However, recent investigations show that OPF had can also bring another commercial value by using it for Biomass Fuel.

Oil palm tree will start bearing fruits after 30 months of field planting and will continue to be productive for the next 20 to 30 years. In Malaysia, the oil palm trees planted are mainly the *tenera* variety, a hybrid between the *dura* and *pisifera*. The *tenera* variety yields about 4 to 5 tonnes of crude palm oil (CPO) per hectare per year and about 1 tonne of palm kernels. For every tonne of palm oil produced from fresh fruit bunches, a farmer harvests around 6 tonnes of waste palm fronds, 1 tonne of palm trunks, 5 tonnes of empty fruit bunches, 1 tonne of press fiber (from the mesocarp of the fruit), half a tonne of palm kernel endocarp, 250 kg of palm kernel press cake, and 100 tonnes of palm oil mill effluent. In efforts to reduce greenhouse gas emissions, scientists treat palm oil mill effluent to extract biogas. After purification, biogas can substitute for natural gas for use at factories. Anaerobic treatment of palm oil mill effluent, practiced in Malaysia and Indonesia, results in domination of *Methanosaeta concilii*. It plays an important role in methane production from acetate and the optimum condition for its growth should be considered to harvest biogas as renewable fuel

2.4 Biomass Drying

(Fagernas et al, 2010) reported that other than conversion, pre treatment of biomass is important including transfer, storage, chipping and drying. From all of the pre treatment, drying is the most challenging process. The important issues in performing drying are energy efficiency, heat emission and dryer performance. Before the synthesis of gas, the feedstocks have to be dried to lower the 30 wt% moisture content to 15 wt%. The size of the feedstock to be dried is depending on the type of dryer used. It is also found that, in drying biomass, organic compound are released as a result of volatilization, steam distillation and thermal destruction. At temperature above 100°C, the condensable organic compound such as fatty acid and resin acid might condense on equipment surface and cause technical problems. Hence, the low material temperature that is below 100°C should be maintained during drying process.(Fagerna et al, 2007) claimed that it is possible to carry out the drying of wood fuels to about 10 wt% moisture without emitting a harmful amount of organic compound.

2.5 OPF energy contain

Base on the data that attained from Enhancement of Biomass Fuel via Torrefaction by Idris M. (January 2011), the energy contain in 1g of OPF without torrefection process is about 16.3 kJ (the same amount of energy are not guaranteed to be recovered in the sync gas produced during gasification process) and this amount of energy could be increase further by applying torrefection process to the OPF until it reach around 23.8 kJ per gram. However in the first place, the torrefection process itself consumes a very high energy where to increase the the energy amount of 7.5 KJ in a gram of OPF we need to supply about 1,000,000 kJ/g, where else, in another example, for increasing the energy amount of 5.24 kJ/g of OPF feedstock, an input of 886810 kJ/g of energy were use for the torrefection process. Base on these data, unless that in the future there are design of suitable torrefaction reactor that can use minimum energy input, so far the process would not be economical wise. The only positive side of this process is it actually can be used to store extra amount of energy inside OPF feedstock so that somehow, will give extra space per energy in storing OPF feedstock.

2.6 Sun Drying

Sun drying is a traditional method used for reducing moister content (MC) of many agricultural products especially. It offers the simplest way in drying process and is best suited for small scale rural operations where product volumes are low (50-199kg of dry product per day). The sun heats earth by sending its powerful rays through radiation. Traditional sun drying takes place by spread and storing the product under direct sunlight. This practice is only possible in areas where, in an average year, the weather allows foods to be dried immediately after harvest. The main advantages of sun drying are low capital and operating costs and the fact that little expertise is required. The main disadvantages of this method are contamination, theft or damage by birds, rats or insects; slow or intermittent drying and no protection from rain or dew that wets the product, encourages mould growth and may result and may result in a relatively high final moisture content; low and variable quality of product due to over or under drying; large areas of land needed for the shallow layers of food; laborious since the crop must be turned, moved if it rain. Furthermore, since sun drying depends on uncontrolled factors, production of uniform and standard products is not expected.

Efficient sun drying requires a combination of sunlight, dry air (low humidity) and good airflow over the product (Natural Resource Institute, 2010). The quality of sun dried products can be improved by reducing the size of drying pieces in order to increase product drying surface and by drying on 30° raised platforms facing the sun to maximize sunlight exposure. Beside intense sunlight, another requirement for sun drying is an adequate supply of air to remove moisture from the surface of the product being dried. Therefore good ventilation is essential during the drying process.

CHAPTER 3
METHODOLOGY

3.1 Overall Project flow

The research project is started by collecting and analyzing the research findings via journals, reference books and discussion with fellow students and supervisor was conducted to have a clearer view of the topic. During experiments, the feedstocks were obtained first by collecting fresh OPF from nearby oil palm estates. The OPF would then be prepared as according to the experiments requirement. Then, the feedstock had gone through drying process which had decrease the moisture content of the feedstock below to 30% weather by furnace drying or by sun drying method. The feedstocks are then stored and ready for the usage in gasification process. The different method of cutting drying and storage are being experimented and will be compared with other relevant collected data to prove their efficiency or their practicality for the industrial usage.

3.2 Research and data gathering

To carry out this project, it is important to fully understand about the properties of the OPF. To compare the practicality of each method, the timescale and the energy usage are being measure and analyze. Reviewing on journals, papers, books and other technical related documents are essential to give insight and basic knowledge about the project. There are also data that being collected by consulting with the industry of Oil Palm production (FELCRA).

3.3 Tools and equipment

The followings are the major tools and equipment that had been used during the experiments for this study: (The tools specifications are attached in Appendices- Table A16)

Figure 3.1: CARBOLITE 450 Oven

Figure 3.2: Grinding Cutter

Figure 3.3: Diesel Motor Granular

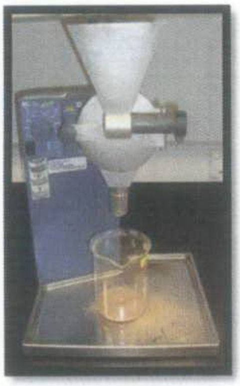


Figure 3.4: Granulator

Figure 3.5: HR73 Halogen Moisture Analyser

Figure 3.6: Digital Weighing Scale

Figure 3.7: Sun Meter

Figure 3.8: Thermometer & Psychrometer

Figure 3.9: Anemometer

Figure 3.10: Sun Drying Stand

3.4 Experimental and analysis

3.4.1 Furnace Drying Experiments

The project started by estimating and confirming the moisture content inside the OPF that should be removed during drying process. Three method of experiments was set up which are continuous drying, non continuous drying by using CARBOLITE 450 Oven and continuous drying using Halogen moisture analyzer. The target of these experiments is to know the percent of moisture content inside OPF besides knowing on how long it would take to dried OPF using oven and furnace. The results had been the benchmark for the other drying experiments later on. For preparing the experiments sample, OPFs were divided into three sections which are petiole (bottom), middle and tip. Then the OPF had been cut into the desired feedstock size which in the size of 2 inch in length and have of between 15 gram to 20 gram. The OPF then dried at $105^{o}C$ in oven for 24 hours with continuous and non continuous drying. Some of the OPF sample is also being ground to small particle (powder form) size using granulator and mortar grinding. The small particles are used in HR73 Halogen Moisture Analyser experiment to determine its moisture content. The data from experiment are recorded and analyze to figure any problem occurrence. The OPF had been collected and experimented repeatedly using different methods and measurement depends on the desired data from study and analysis.

3.4.2 Sun Drying Experiments

Assisted by weather and environment measuring devices,(digital anemometer, psychrometer, thermometer, sun meter) the project continue but focus on attaining data to prove the practicality wise scope of the method in preparing OPF for gasification process. Most of the experiment had been held outdoor as the target is to analysts the practicality of sun drying of OPF for industrial purpose. Some other experiment like cutting and storing were held indoor, certain data and symptoms during cutting storing of OPF are being recorded. In the end of the project, they had been sufficient data to provide for the analysis of how far is the practicality in using OPF source in the country for gasification process.

3.5 Project Planning

The whole project had been conducted in two semesters. The milestone planning for the project is shown in the Gantt chart in Appendices.

3.5.1 Project flowchart

Based on Figure 3.11, the project research begins with data gathering which generally divided into two sections which is data gain from consultation process and data gain from external literature review. For consultation, data are gain from the University representatives like lecturers and post graduates student who involve with gasification projects, meanwhile, for industrial representative, FELCRA officers were being consult. In the other hand, a lot of information was gathered from literature review in the internet, journals, and books and from previous student dissertations. Initial analyses on the information available were performed than specific test and experiment were planned. To perform those specific test and experiments, specific tools and equipments need to be prepare first, this step often need extra research, paperwork for booking purpose, and in some case fabrication process were needed. The test and experiments can be executed after all the equipment and facilities are ready. The data and information gain from the test/experiments is then being analyst and compared with each other. If there is any identification of needing to repeat or modify the test/experiments, then it would be done accordingly. The final result being analyst and from the analysis conclusion were made and future recommendations were identified.

3.5.2 Gantt Chart

The key milestones and project planning is summarized in the Gantt chart in the Appendices.

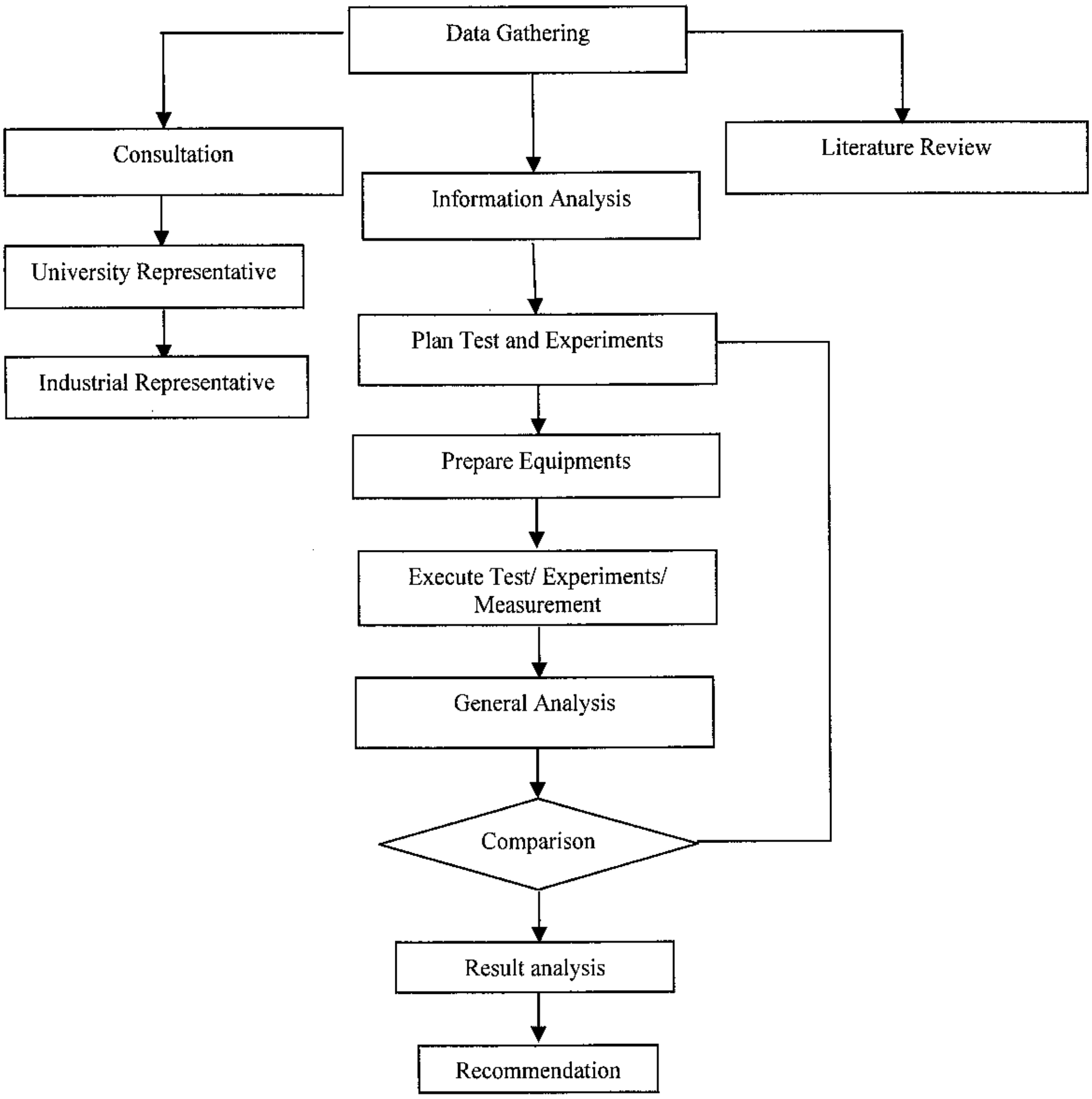


Figure 3.11: Overall Project flowchart

CHAPTER 4

RESULT AND DISCUSSION

4.1 Results

4.1.1 Industrial Early analysis

From a research held by an officer from FELCRA Bhd Nasarudin Belia Plantation in Bota, Perak about oil palm plantation, it is indicate that the total area of the whole plantation covered about 615 hectares. Where else, one hectare of the plantation consist an average 140 of oil palm trees. Each tree are harvested once in 15 days time, which means the trees are harvested twice monthly where in every harvest cycle the plantation gain an average 560 of OPF per hectares. Other conclusion that had been made from the data are a palm tree would produce an average of 8 OPF per month where in one month period, a hectares of oil palm plantation produces 1120 of OPF, which means the whole plantation produces 688 800 of OPF monthly.

4.1.2 OPF feedstock samples preparation

Fresh OPF (not more than one day dropped from the tree) was taken at nearby Oil Palm Plantation (FELCRA Nasarudin). After cutting out the leaves, the OPF are divided into three section which are

1) Tip 2) Middle 3) Petiole

Figure 4.1: Parts of an OPF

All of the OPF samples are then being cut using grind cutter into the required feedstock size which is about 2 inch in length and have the weight in between 15 to 20 gram. Every sample is then being labelled and the mass of every sample are recorded (refer Table A3 in Appendix).


Tip feedstock sample


Middle Feedstock sample


Petiole feedstock sample

Figure 4.2: Labelled Feedstock Samples

4.1.3 OPF Oven Drying Experiments

The samples produced were used in two oven drying experiments and one experiment using HR73 Halogen Moisture Analyzer. The first oven drying experiment is OPF Feedstock Continuous drying experiment and second is the OPF Feedstock Non continuous drying experiment. Both oven drying experiment are using the same type of oven which is CARBOLITE 450 oven. These three drying experiment procedures are attached in the Appendices (Procedures A1, Procedures A2 and Procedures A3)

Table 4.1: Average percentage of weight loss through continuous drying with CARBOLITE 450 Oven

	TIP	MIDDLE	PETIOLE
Avg. % weight loss from 15 hour drying	**68.52%**	**69.42%**	**71.76%**
Avg. % weight loss from 24 hour drying	**68.64%**	**69.63%**	**71.96%**

Meanwhile, from analyzing the OPF Feedstock Non continuous drying experiment data, the average of sample weight loss after 15 hours of drying is 72.66%, and the average of sample weight loss after 24 hours of drying is 71.04%.

In the other hand, from the OPF granule continuous drying experiment using HR73 Halogen Moisture Analyzer experiment, the Sample experience a rapid moisture removal rate for the first hour which is 0.8% per minute, then during the second hour the sample moisture removal rate start to slow which happened at the rate of 0.27% per minute. The moisture removal rate are starting to be rigid for the remaining hour where the sample experience the moisture removal rate of 0.03% per minute, 0.002% per minute, and 0.001% per minute for the third, fourth and the fifth hour respectively. The final moisture % that were successfully removed is 62.62% and it is believe during this level, the sample MC is already reaching 0%.

Table 4.2: OPF Granule Continuous drying experiment using HR73 Halogen Moisture Analyzer Results Summary

Time (hour)	Weight (%)	Weight (g)	Moisture Removed (%)
0	100	18.53	0.00
1	55.92	10.36	44.08
2	39.53	7.32	60.47
3	37.56	6.96	62.44
4	37.44	6.94	62.56
5	37.38	6.93	62.62

4.1.4 OPF sample preparation for sun drying and early analysis

Samples of fresh matured OPF were taken from nearby plantation at early morning. Each OPF samples' leaves were being chopped off and its frond were also being chopped into smaller length at the site due to transportation purpose. The samples are then being prepared and classified into three type of categories which is A (original form), B (the grinded samples, 1-2 inch in length) and C (the chip form samples that was fed into diesel motor granular)

Figure 4.3: Fresh OPF from matured tree taken and the leaves are being cut out.

Figure 4.4: Each OPF being chopped to shorter length for transportation purpose and their initial weight were measured. These three samples being prepared into A, B and C type of categories.

Figure 4.5: Prepared sample A for the sun drying experiments

Figure 4.6: Sample B being prepared by grinding process into smaller size 1-2 inch in length

Figure 4.7: Prepared sample B for the sun drying experiments

Figure 4.8: Sample C being cut to make it thinner, before being feed into diesel motor granular machine

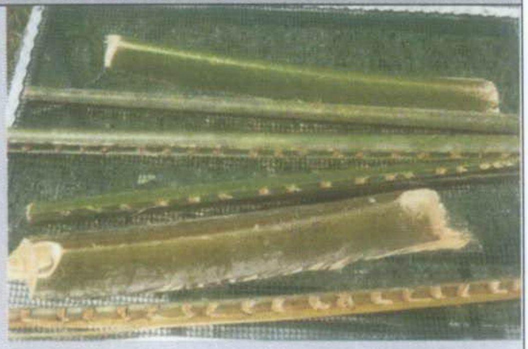
Figure 4.9: Sample C being feed into the granular machine

Figure 4.10: Prepared sample C for the sun drying experiments

4.1.5 Sun Drying Experiments

Two sun drying experiments were conducted on different samples which were prepared using the methods shown in the section 4.1.4 on two different occasions. The OPF samples were collected fresh from the plantation in the early morning of both sun drying experiments. During the first experiment, the samples were dried under the sun for an accumulated of 19 hours in three continuous days. Meanwhile, during the second experiment, the samples were dried under the sun for 8 straight hours on one day. These two sun drying experiment procedures are attached in the Appendices (Procedures A4 and Procedures A5)

Table 4.3: Change of appearance between fresh samples before sun drying and after 3 days of sun drying

Sample	Fresh Samples	After 3 Days Drying
A – One whole of a fresh OPF without leaves being cut into 6 pieces		
B – One whole of a fresh OPF without leaves being grinded from petiole until the tip into about 2 inch in length each		
C – One whole of a fresh OPF without leaves being feed into granular and turned into chip form		

After 3 days of sun drying, the different of properties from different samples could be seen from the texture between the fresh and dried samples. Dried samples turn brownish depends where in most of the cases, the more MC that being removed, the more brownish the texture of the samples should be. The dried samples are also very light and crunchy compare to the fresh samples. There is nothing much change happens to sample A because it still have high amount of MC left after the 3 days of sun drying.

Table 4.4: Change of appearance in samples between fresh samples before sun drying and after one day of sun drying during hot and sunny weather

Sample	Before	After
B2 - One whole of a fresh OPF without leaves being grinded from petiole until the tip into about 2 inch in length each		
C2 - One whole of a fresh OPF without leaves being feed into granular and turned into chip form		

After one day of sun drying during a hot and sunny day, the different of properties from different samples could be seen from the texture between the fresh and dried samples. Dried samples turn brownish depends where in most of the cases, the more MC that being removed, the more brownish the texture of the samples should be. The dried samples are also very light and crunchy compare to the fresh samples. Compare to the result from the 3 days sun drying experiment, sample B2 and C2 are less brownish and looks fresher.

4.1.7 OPF Storing

A few storing conditions were tested to prove any changes experience by the OPF if it is being stored. Varieties storage condition were recorded like storing fresh samples in open air and close air condition and storing dried condition in open air and close air condition. All of the storing experiments were done in room condition. Figure 4.11 below shows how two similar samples are being stored in a room but with two different conditions which one are stored with an open air and the other one are stored inside a closed container start from the first day it was taken fresh from the oil palm plantation.

Figure 4.11: Fresh (wet) sample are being stored in two condition (open air, close air) (refer to Table A12 in Appendices for data of the experiment)

On the other hand, figure 4.12 show the change of appearance happened to the OPF samples stored inside the closed container after it being stored for 3 days and 7 days continuously. Besides being wet and sweaty, the samples colour is turning brownish and the samples increasingly emit foul odour from day to day. Because of the samples are soaking in wet condition, the samples texture are also softening after a few days.

Figure 4.12: Fresh (wet) sample after 3 days and after 7 Days

From other storing experiment, Figure 4.13 below shows how a few sun dried samples from previous sun drying experiments are being stored under room condition. The samples are not being sealed in any container.

Figure 4.13: Three days sun dried sample are being stored in room condition (refer to Table A13 in the Appendices for the experiment data)

The last storing experiment is about storing oven dried samples which the samples were stored in closed container right after it being dried in oven to the point of close to 0% in moisture content. Figure 4.14 below shows how the sun dried samples being stored in closed container and being kept on a shelf inside a normal room condition.

Figure 4.14: Dried samples are being stored in room condition (refer to Table A14 in the Appendices for the experiment data)

4.2 Discussion and Analysis

1. From the continuous drying results, this by using CARBOLITE 450 oven and HR73 Halogen Moisture Analyzer, a graph of mass over time is plotted. Figure 4.15 indicate on how every samples loss it mass due to the loss of moisture content versus time while Figure 4.16 is plotted on the samples average loss of mass due to the loss of moisture content versus time.

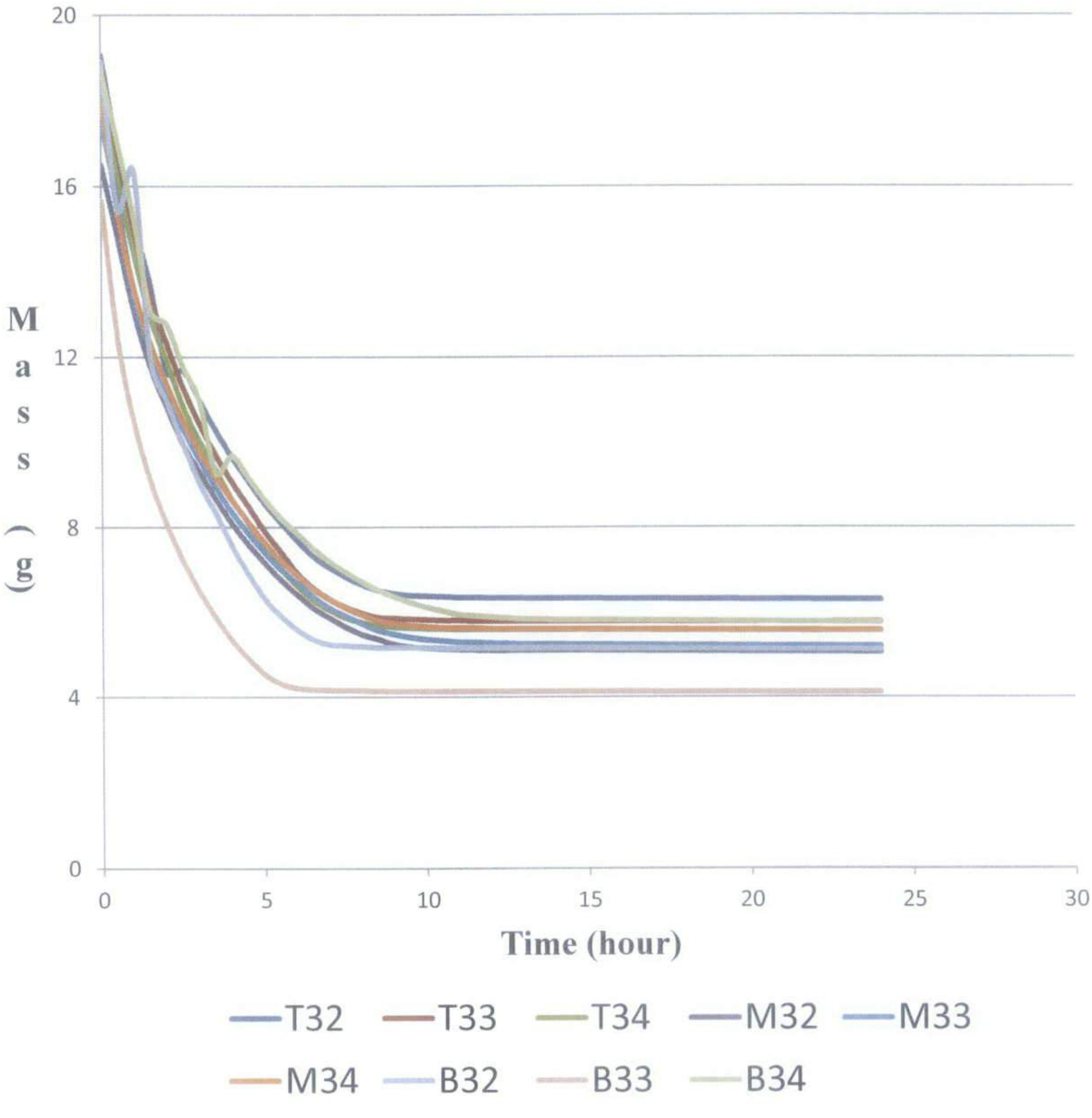


Figure 4.15: OPF Feedstock Drying with Carbolite 450 Oven (T=105 °C)

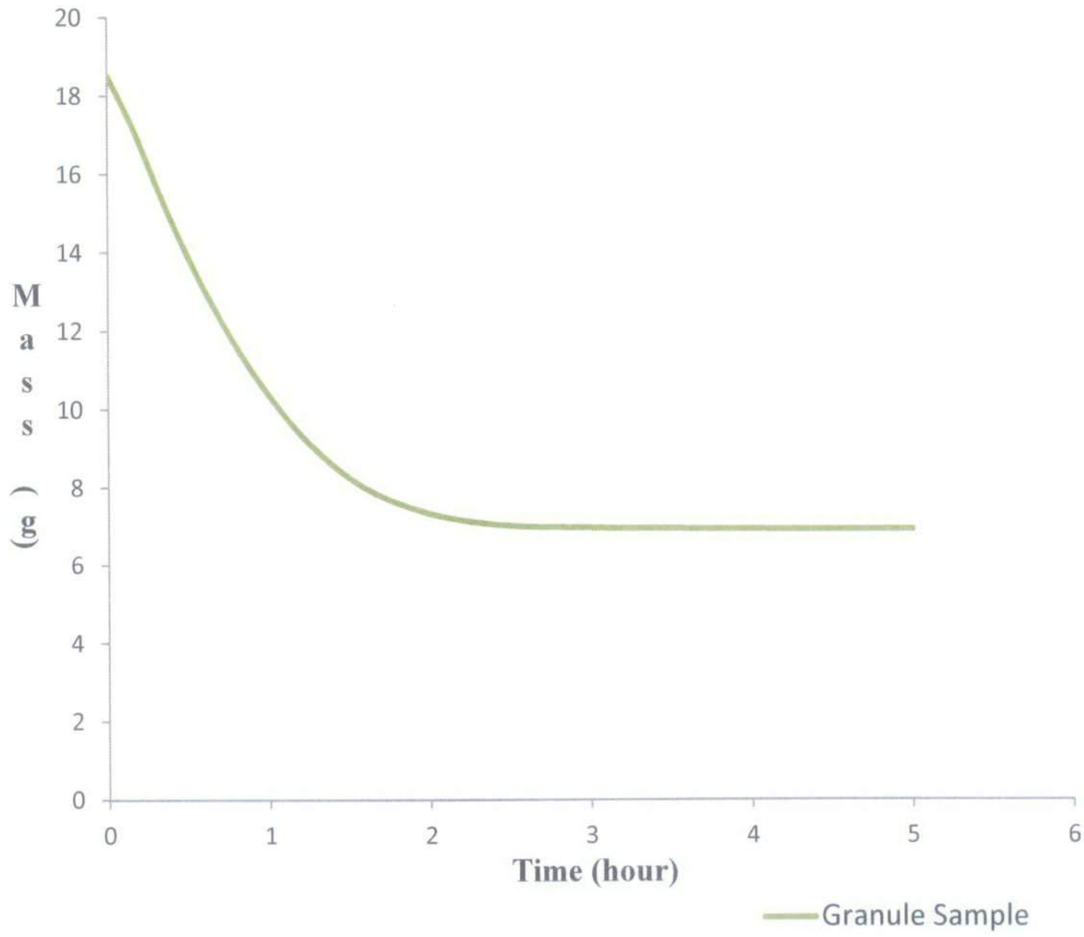


Figure 4.16: OPF Powder Granule Drying With HR73 Halogen Moisture Analyzer (T=105 °C)

2. The maximum moisture removal recorded in OPF Granule Continuous drying experiment using HR73 Halogen Moisture Analyzer experiment is about 62.62% which less than the average value found using CARBOLITE 450 oven which is up to 72%. One of the reasons in this case is the samples used in Halogen Moisture Analyzer are smaller in weight as compared to the above samples. The other possible reason is because the feedstock samples we select for Drying with CARBOLITE 450 Oven have hard shell surface. From other the other experiment we have observed that the samples which are found near to the external part of OPF (near to the hard shell) has less moisture content and more slow moisture removal rate.

3. The reason for a lower moisture content of OPF in OPF Powder Granule Drying with HR73 Halogen Moisture Analyzer Experiment is due to the change of nature of the

OPF structure during the granulation process. To support these, we should know that the nature of OPF structure that trap water is because of it is consist of porous horizontal fibres that stack together and this water trapping fibres are being shelled with a hard smooth non-porous surface. To understand this in a simpler manner, we could say that the original OPF structure is like a sponge that traps water and the sponge surface is being covered with water proof layer. It is believe that some of the original moisture content in the OPF was already lost during granulation/powdering process because during the process, some part of the OPF were being crushed causing some of the moisture being release. If we understand that the powder/granular form of OPF already lost its original structure that trap moisture, we should know that the moisture of the powder structure could easily lost to the atmosphere before the drying process inside the Halogen Moisture Analyzer begin this is include during the process of transporting the OPF powder from granular to the analyzer. The OPF powder granule high area surface per volume is also a factor that causing OPF moisture content are easily lost in the atmosphere due to evaporation process.

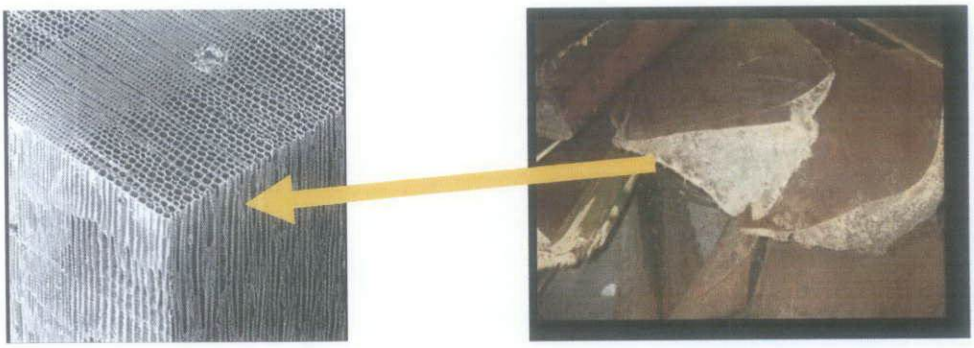


Figure 4.17: Oil palm frond microstructure

4. After analyzing the data from the OPF feedstock continuous drying experiment using CARBOLITE 450 Oven, the experiment shows that the OPF samples experience average weight loss of 69.90% after 15 hour of oven drying and average weight loss of 70.07% after 24 hour of oven drying. In the other hand, from analyzing the data from OPF non continuous drying using CARBOLITE 450 oven, the OPF sample experience a weight loss 72.66% of after 15 hour of oven drying and sample weight loss of 71.04% after 24 hour of oven drying. However, during the non continuous drying, the OPF samples experience a slide gain in moisture content during the samples weight measuring process which made the result from this experiment is slightly inaccurate. Base on this reason, the result from the non continuous drying is not applicable. From further data analysis, we could also see that, there is only 0.17% different of weight loss if we continue to dry the OPF for another 9 hours after 15 hours of oven drying. This shows that, it is impractical to continue the drying process after 15 hour because it should consume unnecessary energy to eliminate insignificant amount of moisture. To assume the most cost efficient time for oven drying of OPF feedstock, we refer to Figure 4.15. The graph show that 8 to 10 hours of fresh OPF feedstock oven drying should be enough to eliminate the OPF feedstock moisture content into its minimum level.

5. From the continues 3 days of sun dry experiment on 3 group of samples (A, B, C) the graph of weight lost over time is plotted.

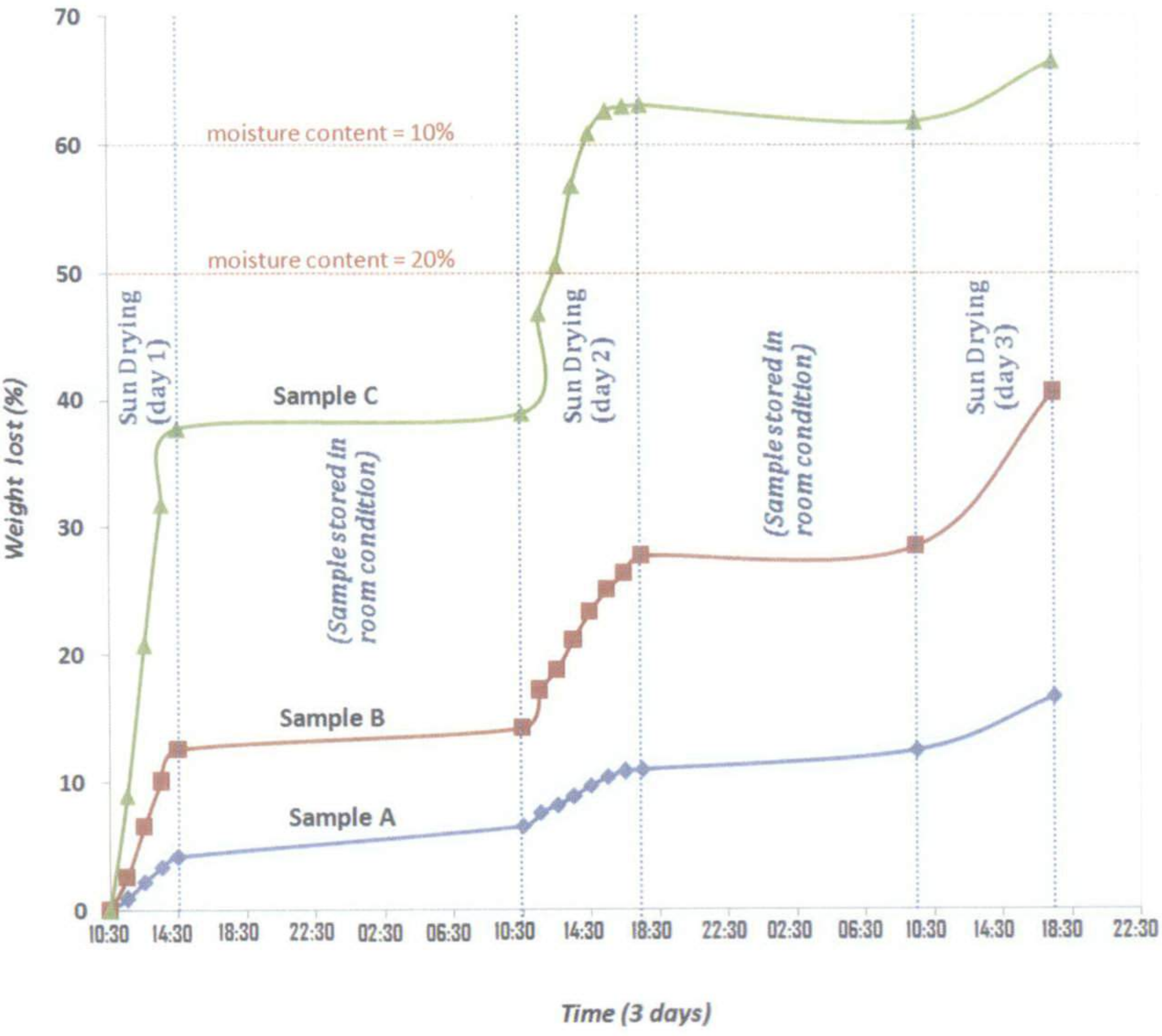


Figure 4.18 Variation of weight loss with drying time for 3 days of Sun Drying

6. Referring to figure 4.18, on the first day (cloudy weather), the sun drying process of samples was held for 4 hours which is from 10:30 am until 2:00 pm. During this time, sample A lost 4.2% of MC at rate of 1.05% per hour, while sample B lost 12.6% of MC at rate of 3.15% per hour, and sample C lost 37.75% of MC at rate of 9.45% per hour (refer to Figure A3 in Appendix). After 2:00 pm, because of raining, the samples are kept under room condition for about 20 hours which is until 10:30 am of the next day. During this period, all samples keep losing a small amount of MC where sample A lost 2.33% of MC at rate of 0.12% per hour, meanwhile sample B lost 1.65% of MC at rate of 0.08% per hour, and sample C lost 1.15% of MC at rate of 0.06% per hour.

On the second day (cloudy weather), the sun drying process was held for 7 hour starting at 10:30 am until 5:30 pm. During this period, sample A lost 4.5% of MC at rate of 0.64% per hour, meanwhile sample B lost 13.48% of MC at rate of 1.92% per hour and sample C lost 24.06% of MC at rate of 3.43% per hour (refer to figure A4 in Appendix). After 5:30 pm, the samples then are kept under room condition for about 16 hours which is until 9:30 am of the next day. During this period sample A and B keep losing small amount of MC while sample C gain some amount of MC, where sample A lost 1.5% of MC at rate of 0.09% per hour, while sample B lost 0.7% of MC at rate of 0.04% per hour, and sample C gain 1.3% of MC at rate of 0.08% per hour. This phenomena show that sample C is already dried after 2 days, where the MC in sample C is already lower than then moisture level of the atmosphere in the room. During this level we could say that sample C is already hypertonic compare to the room atmosphere causing it to gain moisture in a natural process to be in equilibrium with the room in term of moisture level. Although sample C is regaining moisture, it is very minimal and negligible because the sample moisture content level is still at a low and safe level which is lower than 10%.

On the third day (sunny weather), the sun drying process was held for 8 hour starting at 9:30 am until 5:30 pm. During this period, sample A lost 4.2% of MC at rate of 0.53% per hour, while sample B lost 12.1% of MC at rate of 1.51% per hour and sample C lost 4.7% of MC at rate of 0.59% per hour (refer to figure A5 in Appendix).

Table 4.5: Summary on Samples Condition after 3 days

Sample	**Sun Drying (day 1)**		**1st Storing Period**		**Sun Drying (day 2)**		**2nd Storing Period**		**Sun Drying (day 3)**	
	MC % change	%/hour	MC % change	%/hour	MC % change	%/hour	MC % change	%/hour	MC % change	%/hour
A	-4.2	-1.05	-2.33	-0.12	-4.5	-0.64	-1.5	-0.09	-4.2	-0.53
B	-12.6	-3.15	-1.65	-0.08	-13.48	-1.92	-0.7	-0.04	-12.1	-1.51
C	-37.75	-9.45	-1.15	-0.06	-24.06	-3.43	1.3	0.08	-4.7	-0.59

7. From the 1 day of sun drying experiment during a sunny day on 2 group of samples (B2 , C2) the graph of weight lost over time is plotted.

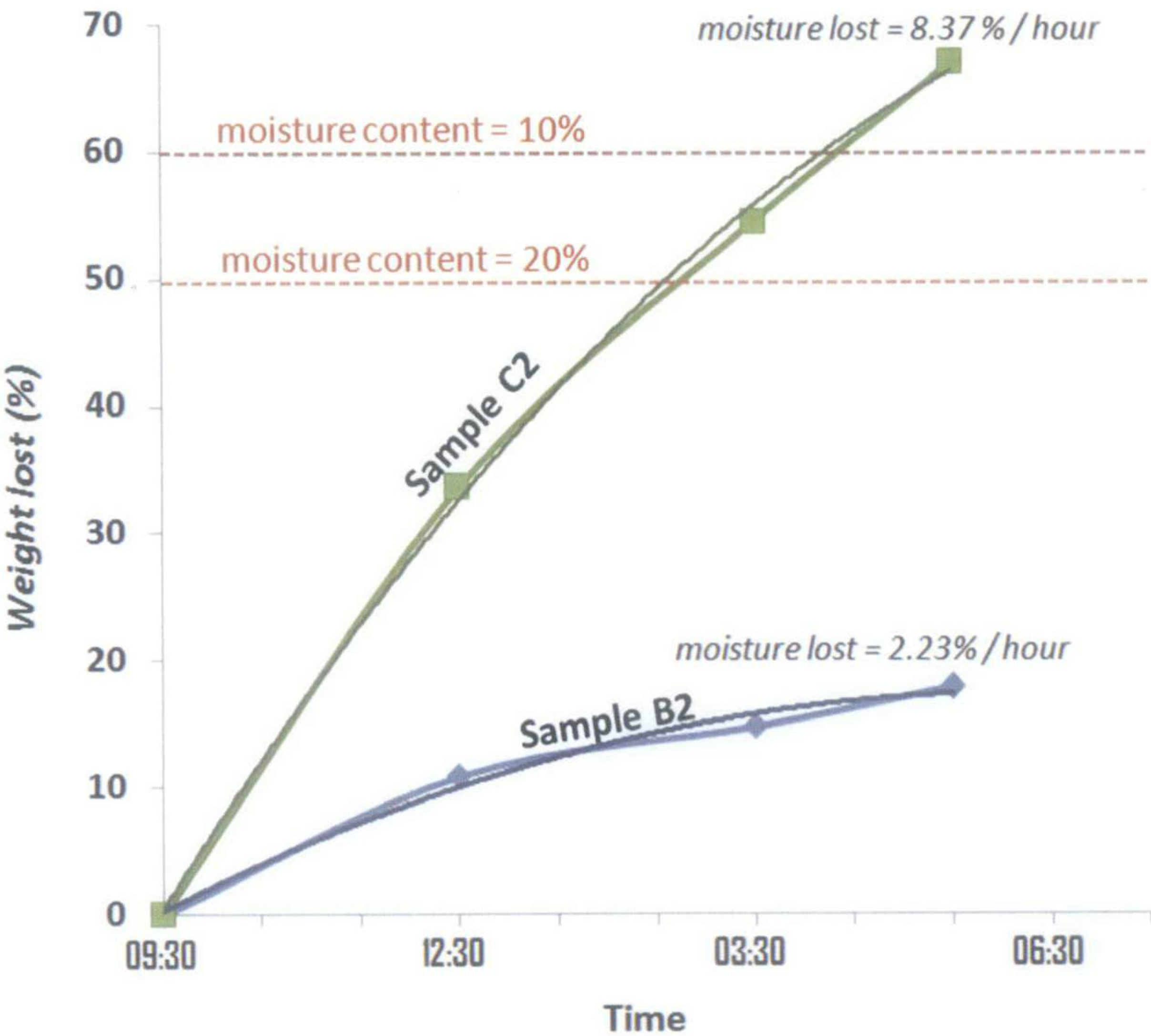


Figure 4.19: 1 Day Sun Drying (Hot and Sunny Weather)

8. Referring to Figure 4.19, the sun drying of samples was held for 8 continues hour which is from 9.30 am until 5.30 pm. During this period of time, sample C2 experience a rapid loss of moisture content referring to its rapid loss in weight which is in the rate of 8.37% / hour while sample B2 experience a slower rate of moisture content loss which is only at the rate of 2.23% / hour. The rapid loss of moisture content in C2 sample indicate that sample C2 is safe to be feed into any gasifier (moisture content < 20%) after being sun dried for a period of 6 hour and the sample should be save to be store (moisture content < 10%) after being sun dried for the period of 8 hour. When we refer to the sample C in Figure 4.18, although the sun dry was held during cloudy weather, if we add the amount of period of sun drying in the 1st day and 2nd day, it also

shows that the same result which is sample category C (chip sample), if it experience sun drying in the period of 6 hour it should be safe to be feed into any gasifier, and if the sample experience sun drying in the period of 8 hour it should be enough for it to be save for storing.

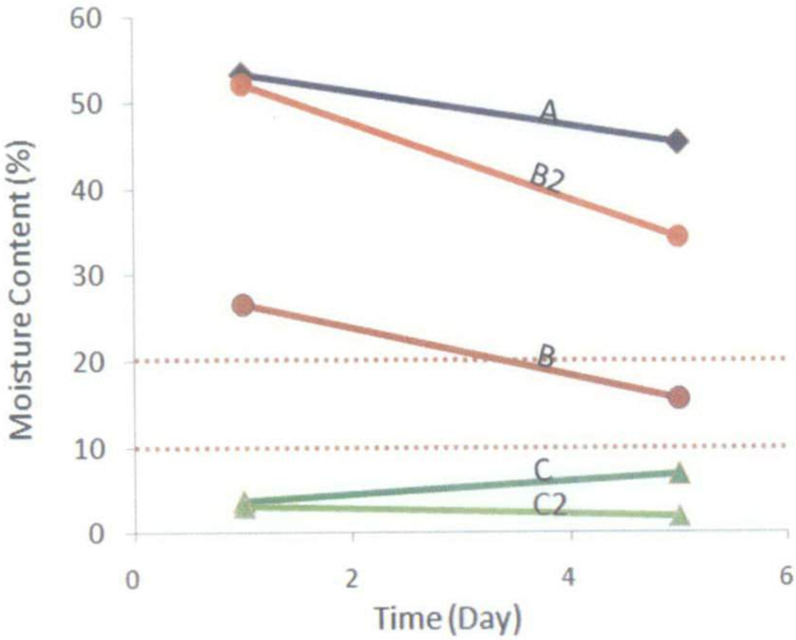


Figure 4.20: Variation of moisture content with time for OPF samples after being stored for 5 days in an open air room condition

9. Referring to Figure 4.20 (graph of moisture content over time plotted base on the table A 6), we could see that sample category A and B continue to experience loss in moisture content (assumed all samples have 70% MC in their original fresh condition). In the other hand we could see that sample C is gaining its MC but sample C2 is still losing MC to the atmosphere. However, the changes of moisture content in both C category samples are marginal where the MC level of both samples is still in the save zone for storing purpose (MC < 10%). In the meanwhile, (refer to Table A6 in Appendix) during those 5 days, sample A is experience 7.89% loss in MC in the rate of 1.578% per day, while sample B experience 11.08% loss of MC in the rate of 2.216% per day and sample B2 experience 17.91% loss in MC in the rate of 3.582% per day. Sample B has reach the level of moisture content <20% after day 3 which mean it is already safe to be use as feedstock for gasification.

10. Base on the data provided from the 3 days sun drying experiment, a graph of variety properties over time is plotted. This graph covers 4 + 7 hour of sun drying process that was conducted during the 1st two days. The function of plotting this graph

is to compare the similarities of patterns between weather factors and rate of MC change over time, then analyst which of the factor that affect the rate of MC changes the most. Referring to the graph (Figure 4.21), the most accurate factor of weather that affect the rate of MC changes is the sun ray intensity. It is proven where rate of moisture change would decrease whenever sun ray intensity decreases, and rate of moisture change would increase whenever sun ray intensity increases.

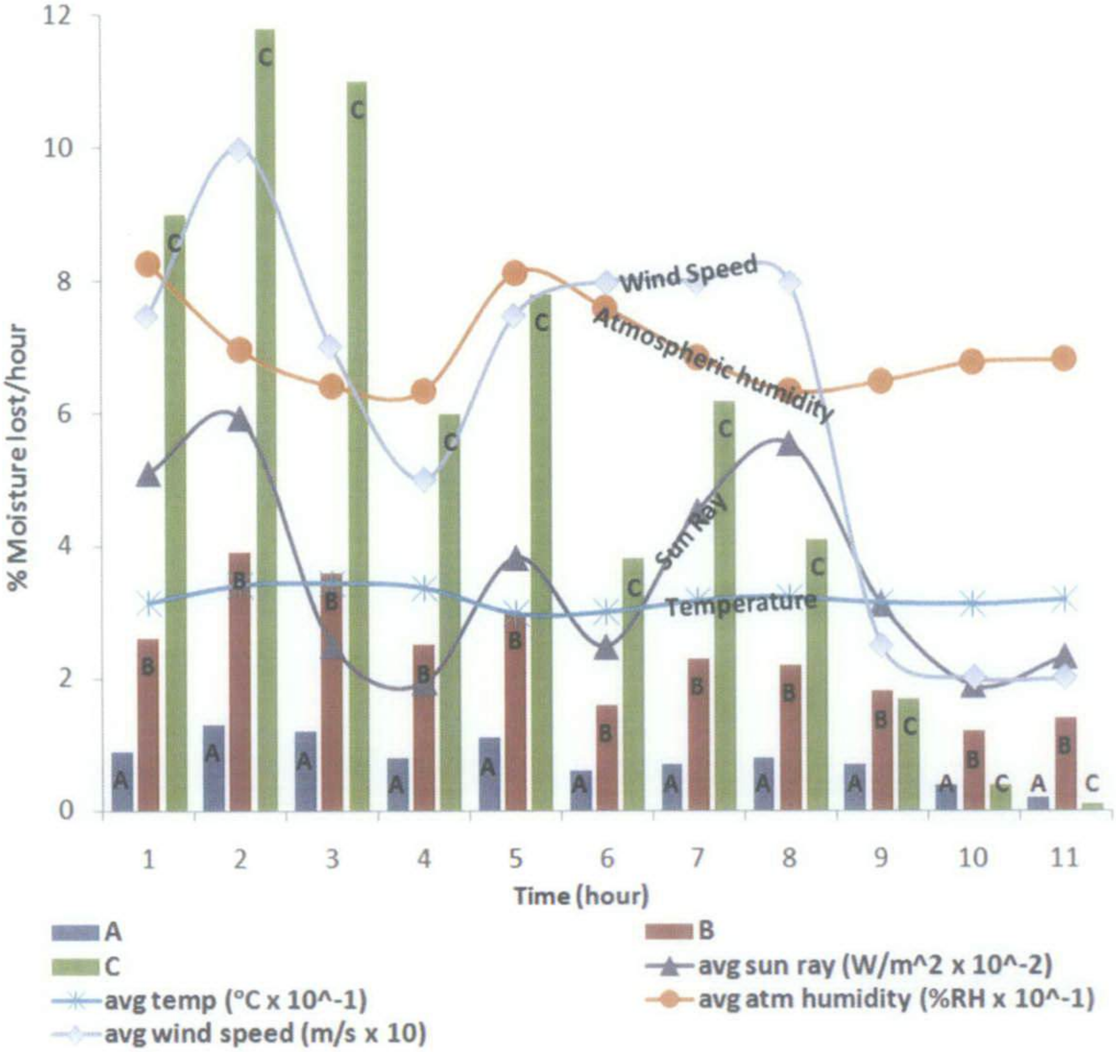


Figure 4.21: Various weather factors and its effect on moisture lost of the OPF samples during sun drying versus time

11. Referring to the data provided in the table A12 regarding fresh OPF sample storing, Figure 4.22 below is plotted. The graph consists of two Y axis which is Weight (%) of OPF sample and rate of sample Weight loss/day (%) and it has two set of samples which are open air storing sample and close air storing sample. The function of this graph is to indicate the change of mass of the OPF samples over time in the period of a week. The graph indicates that fresh OPF could loss its moisture content in room condition if the ventilation is not being sealed. From the graph, it is predicted that the fresh OPF sample that being stored in normal room condition with open air could reach the level of MC below 20% in the period of 2 weeks. However, from the experience, the sample will release bad odour and are very vulnerable to fungal and microbial attack that would cause the decrease of sample energy value.

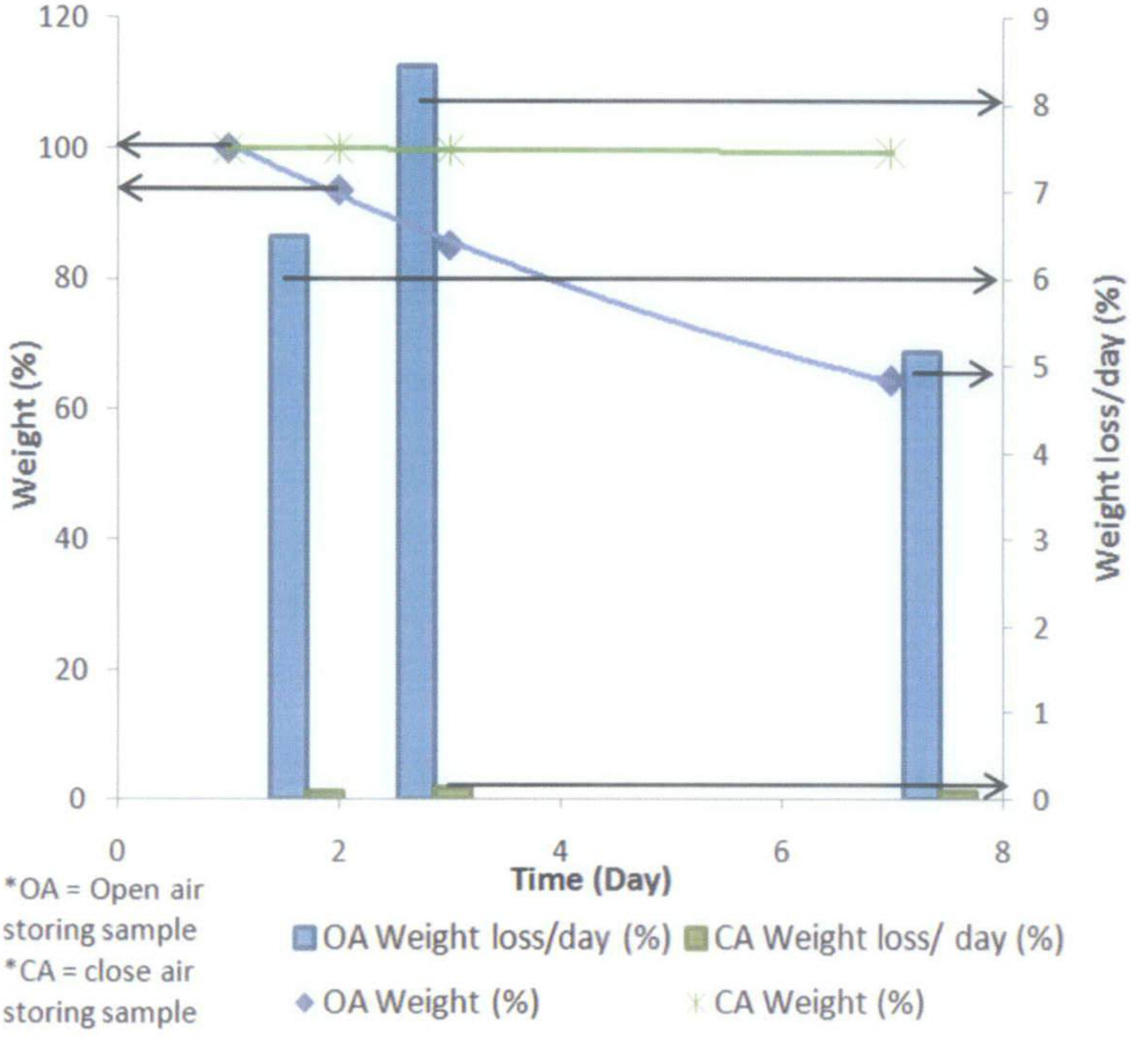


Figure 4.22: Fresh OPF Storing in Room Condition (Open Air and Close Air)

12. Base on the storing of 28 oven dried samples (refer to Table A14); Figure 4.23 is plotted by taking the 28 samples average data. The function of the graph and the experiment entirely is to indicate if there is any major changes to dried OPF sample if it being stored properly in a sealed container for a long period of time. Base on the results, the conclusion is dried OPF that being stored in a sealed container shall gain a certain amount of moisture contain but the change is very marginal and would not decrease the feedstock value even though it is stored for more than 4 month.

Figure 4.23: Average Result for Stored Samples (After 134 days)

13. Industrial post analysis:

Base on data obtain from FELCRA Nasarudin, in Bota, Perak which covers about the plantation area and its production, a few important information are pointed in the table 4.6 below

Table 4.6: Data obtained from FELCRA Nasarudin, Bota and analysis

Plantation Total Cover, $\sum A$	615 hectares
Average one hectares	140 of Oil Palm Trees
Harvest Cycle	15 days or twice per month
One Cycle	560 OPF per Hectares
Average space needed to spread 1kg of fresh chipped OPF	0.14 m^2/kg
Average weight of fresh mature OPF	2.5 kg
Average weight of dried mature OPF	0.75 kg

Which mean, for every one month or during 2 harvest cycles the production rate are:-

Avg. a Tree	8 of OPF; 20kg of fresh OPF; 6 kg of dried OPF
Avg. One Hectares	1120 of OPF; 2800 kg of fresh OPF; 840 kg of dried OPF
Whole plantation produces	688,800 of OPF

For every cycle the space required for drying are :-

A Tree per cycle	1.4 m^2 or 0.00014 hectares
One Hectares per cycle	196 m^2 or 0.0196 hectares
TheWhole 615 hectares of plantation per cycle	120,540 m^2 or 12.054 hectares

CHAPTER 5
CONCLUSIONS & RECOMMENDATIONS

The study on OPF preparation for biomass gasification is important to overcome the problem related to utilizing OPF for biomass gasification before introducing it for industrial purpose. The problem related in turning any OPF into a ready use feedstock for biomass gasification are basically consist in three process which are cutting, drying and storing the OPF. The objective of these studies is to provide prove and viable suggestion in preparing OPF for biomass gasification purpose.

5.1 Conclusions

The first part of this project is to study the properties of OPF in order to relate it to OPF requirement in its preparation process for biomass gasification. Moisture level of feedstock is the key factor in preparing OPF for biomass gasification. Fresh OPF samples were dried at 105°C for 24 hours in order to found out the average OPF moisture level where it is conclude that we can assume that every fresh OPF has around 70% of moisture content. The safe level of moisture content for any feedstock to be feed into any gasifier is to be under 20%. Meanwhile, in order to store and preserve OPF as biomass feedstock without losing its value, the OPF should have no more than 10% moisture content. Therefore base on the average analysis, any OPF that its weight has been reduce 50% from its original mass in drying process, should be safe to be feed into gasifiers. In the other hand, any OPF that its weight has been reduce 60% from its original mass in drying process, should be sufficient to be preserve and store for more than 4 month period without facing any major decrease in its value. Oven/furnace drying are proven to be not practical and very costly compare to sun drying. While oven drying would need 4 hours of drying time to reduce OPF MC until it reach under 20% and need 7 hours of drying time to reduce OPF MC until it reach under 10%, the sun drying need maximum of 6 hour of drying time to reduce OPF MC until it reach under 20% and need 7 to 8 hours of drying time to reduce OPF MC until it reach under 10%. The only disadvantages that sun drying posses compare to oven drying is it's dependency on weather, other factor than that is a major advantage like in term of the cost, technical requirement, and practicality.

The project has successfully met the objective which is to provide the practical method in preparing OPF in order to produce a cheaper and more efficient biomass fuel from biomass gasification using OPF as the feedstock.

5.2 Recommendation

Base on the findings in the studies and experiments, there are a few recommendation that could be made in preparing OPF for biomass gasification.

Preparing Method:

There are two major factor regarding cutting of OPF in order to increase the moisture removing rate of OPF during drying process. First is to decrease the OPF surface area by reducing the OPF granule size and secondly is to crush the OPF granule in order to squeeze out the moisture contain inside the OPF pore. The crushing mechanism on OPF would also tear down the OPF water trapping structure and when the OPF original structure are changed, the drying process should happen more rapidly and easily.

Wood chipper provide both major factor where it has crushing mechanism perform by the rollers and the fine cutting mechanism to cut OPF into finer/smaller sizes (refer to Figure A7). Wood chipper is also easily available to be purchased, affordable, and have varieties of type depending on the usage scale.

Sun drying is the best practical method that should be use in drying OPF for biomass gasification. There are two major requirement needed in optimizing sun drying method which are provide good ventilation and maximize sun exposing area. Therefore, to build a simple drying stand it should equipped with mosquito mesh drying surface or fine netting and the drying surface should be lifted high enough from the ground level to provide ventilation on top and below the drying surface (refer Figure A8 and Figure A10), meanwhile to maximize its sun exposing area the stand should be build or should be placed with 30^{o} inclined surface towards the sun (refer Figure A9). The inclination should not be more than 30^{o} to avoid sample slipping from the drying surface. To help with drying the product should be turn frequently (hand broom could be used). If rain is expected the drying stand/rack should be taken under cover immediately. Using this method, drying should be completed within six to eight hours.

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APPENDICES

5.1 Gantt chart

Table A1: Gantt chart for first semester, FYP 1

Details	Week 1	2	3	4	5	6	7		8	9	10	11	12	13	14
election of Project Topic	■							MID SEMESTER BREAK							
irst meeting with supervisor		■													
reliminary Research work															
) Research the detail about Oil Palm Frond (biological, iechanical, chemical, history)		■	■	■	■	■	■								
) Research about Biomass		■	■	■	■	■	■								
) Research about Mechanical Testing and Properties		■	■	■	■	■	■								
'reliminary Report preparation			■	■											
ubmission of Preliminary Report (20 August 2010)				●											
eminar 1 (optional)					■	■	■								
'rogress report preparation							■								
ubmission of Progress Report									●						
tesearch about Drying Method							■		■	■	■				
:xecute Experiment										■	■	■	■		
'rocess data and Analysis											■	■	■	■	■
)iscussion and Method Alteration											■	■	■	■	■
eminar 2 (compulsory)										■	■	■	■		
ubmission of Interim Report Final Draft														●	
)ral Presentation preparation													■	■	
)ral Presentation (Week 14)															●

Table A2: Gantt chart for first semester, FYP 2

Details	Week 1	2	3	4	5	6	7		8	9	10	11	12	13	14
iterature review	■	■	■	■	■	■	■	MID SEMESTER BREAK	■	■	■	■	■	■	■
)PF source collection	■	■	■	■	■	■	■		■	■	■	■	■	■	
irinding and drying of biomass	■	■	■	■	■	■	■		■	■	■	■	■	■	
ubmission of Progress Report I			■												
utting Experiment	■	■	■	■	■	■	■		■						
)rying Experiment	■	■	■	■	■	■	■		■						
ubmission of Progress report 2 and eminar									■						
toring Experiment	■	■	■	■	■	■	■		■						
Aethod Designing		■	■	■	■	■	■		■	■	■	■	■	■	
Aethod experiment and analysis				■	■	■	■		■	■	■	■	■	■	
inal Analysis													■	■	■
ubmission of Dissertation Final Draft															■

Suggestion milestone ● Process ■

APPENDICES

Table A3: Feedstock Sample Initial Mass

Tip		Middle		Bottom	
Sample No	Mass (g)	Sample No	Mass (g)	Sample No	Mass (g)
1	19.54	1	18.11	1	15.95
2	18.69	2	19.73	2	19.79
3	18.68	3	16.56	3	19.13
4	17.48	4	19.70	4	17.24
5	18.15	5	17.23	5	17.98
6	18.01	6	17.53	6	18.86
7	18.29	7	19.74	7	18.56
8	15.23	8	17.17	8	17.74
9	18.00	9	16.59	9	15.91
10	18.69	10	18.66	10	18.14
11	18.78	11	15.35	11	17.41
12	17.81	12	18.44	12	18.75
13	19.01	13	19.76	13	15.65
14	17.68	14	17.96	14	15.51
15	16.93	15	15.60	15	19.59
16	17.27	16	15.69	16	16.35
17	17.81	17	17.72	17	19.16
18	16.99	18	18.10	18	18.96
19	19.11	19	17.32	19	17.60
20	17.50	20	15.94	20	16.83
21	17.24	21	16.17	21	18.81
22	16.65	22	16.32	22	15.87
23	18.57	23	17.25	23	18.12
24	19.02	24	16.79	24	18.95
25	15.61	25	16.13	25	18.23
26	19.62	26	19.32	26	18.48
27	19.36	27	19.01	27	18.00
28	17.99	28	16.61	28	19.04
29	18.00	29	18.88	29	19.43
30	17.20	30	18.73	30	19.56
31	17.95	31	17.95	31	18.92

Table A4: Continuous Drying With CARBOLITE 450 Oven Results

Time (hour)	Mass (g)								
	Tip			**Middle**			**Bottom**		
	T32	T33	T34	M32	M33	M34	B32	B33	B34
0	19.06	18.89	18.21	16.51	17.55	18.08	18.92	15.66	18.70
0.5	16.91	16.66	16.19	14.80	15.66	15.43	15.45	12.39	17.03
1.0	15.14	14.71	14.43	13.07	13.47	13.60	*16.37	10.44	15.25
1.5	13.70	13.40	12.95	11.76	12.15	12.32	11.96	9.08	13.08
2.0	11.65	12.32	11.90	10.82	11.18	11.35	10.97	8.05	12.77
2.5	11.69	11.28	10.84	9.95	10.33	10.51	9.96	7.20	11.77
3.0	11.00	10.44	10.03	9.31	9.61	9.78	9.05	6.48	10.98
3.5	10.28	9.70	9.36	8.67	8.95	9.20	8.33	5.87	*9.30
4.0	9.66	9.07	8.66	8.09	8.36	8.65	7.55	5.33	9.69
4.5	9.10	8.50	8.12	7.60	7.87	8.13	6.90	4.90	9.18
5.0	8.56	7.91	7.51	7.16	7.41	7.65	6.31	4.53	8.67
5.5	8.11	7.42	7.03	6.76	7.01	7.22	5.90	4.31	8.22
6.0	7.69	6.92	6.62	6.41	6.68	6.87	5.58	4.21	7.86
6.5	7.31	6.56	6.27	6.09	6.35	6.53	5.35	4.17	7.50
7.0	7.05	6.30	6.05	5.86	6.09	6.30	5.24	4.16	7.19
7.5	6.83	6.11	5.86	5.64	5.90	6.09	5.21	4.15	6.94
8.0	6.64	5.97	5.75	5.47	5.72	5.93	5.19	4.15	6.71
8.5	6.51	5.87	5.68	5.36	5.56	5.80	5.16	4.14	6.51
9.0	6.43	5.85	5.64	5.24	5.47	5.72	5.16	4.13	6.35
9.5	6.39	5.83	5.62	5.18	5.40	5.68	5.16	4.13	6.22
10.0	6.37	5.82	5.61	5.15	5.35	5.65	5.16	4.13	6.11
10.5	6.36	5.80	5.60	5.13	5.32	5.63	5.15	4.13	6.02
11.0	6.34	5.80	5.59	5.12	5.29	5.62	5.15	4.13	5.94
11.5	6.34	5.79	5.59	5.11	5.28	5.62	5.15	4.13	5.91
12.0	6.33	5.79	5.59	5.10	5.27	5.61	5.15	4.13	5.88
12.5	6.33	5.79	5.59	5.10	5.26	5.60	5.15	4.13	5.86
13.0	6.33	5.79	5.59	5.10	5.25	5.60	5.15	4.13	5.84
13.5	6.32	5.79	5.59	5.10	5.25	5.60	5.15	4.13	5.83
14.0	6.32	5.79	5.59	5.10	5.25	5.60	5.15	4.13	5.82
14.5	6.32	5.79	5.59	5.10	5.24	5.60	5.15	4.13	5.82
15.0	6.32	5.79	5.59	5.10	5.24	5.60	5.15	4.13	5.82
24.0	6.29	5.77	5.56	5.06	5.20	5.57	5.12	4.11	5.76

* Wrong readings

Table A5: Non Continuous Drying With CARBOLITE 450 Oven Results

	Tip			Middle			Bottom		
Time (hr)	Sample	M_i	M_f	Sample	M_i	M_f	Sample	M_i	M_f
0.50	**T9**	18.00	16.74	**M1**	18.11	16.69	**B1**	15.95	13.72
1.00	**T15**	16.93	14.80	**M19**	17.32	14.09	**B6**	18.86	15.02
1.50	**T18**	16.99	12.45	**M23**	17.25	12.45	**B15**	19.59	15.37
2.00	**T12**	17.81	13.40	**M18**	18.10	11.21	**B11**	17.41	11.77
2.50	**T14**	17.68	11.60	**M14**	17.96	10.65	**B19**	17.60	11.56
3.00	**T21**	17.24	10.20	**M27**	19.01	10.35	**B18**	18.96	12.46
3.50	**T24**	19.02	11.35	**M22**	16.32	7.60	**B23**	18.12	9.68
4.00	**T27**	19.36	10.08	**M26**	19.32	8.25	**B14**	15.51	7.08
4.50	**T26**	19.62	10.93	**M17**	17.72	7.80	**B10**	18.14	6.65
5.00	**T31**	17.95	7.63	**M21**	16.17	6.23	**B9**	15.91	5.09
5.50	**T20**	17.50	7.06	**M20**	15.94	6.32	**B13**	15.65	4.92
6.00	**T17**	18.34	7.91	**M24**	16.79	6.47	**B7**	18.56	5.66
6.50	**T23**	18.57	6.34	**M10**	18.66	7.15	**B8**	17.74	5.12
7.00	**T5**	18.15	7.21	**M15**	15.60	4.56	**B12**	18.75	6.68
7.50	**T11**	18.78	6.73	**M31**	17.95	5.73	**B16**	16.35	5.95
8.00	**T30**	17.20	6.19	**M11**	15.35	4.19	**B17**	19.16	5.48
8.50	**T8**	15.23	4.94	**M25**	16.13	4.15	**B20**	16.83	6.01
9.00	**T29**	18.00	5.23	**M30**	18.73	6.21	**B22**	15.87	4.06
9.50	**T13**	19.01	6.50	**M29**	18.88	5.40	**B27**	18.00	4.90
10.00	**T10**	18.69	6.13	**M13**	19.76	6.63	**B26**	18.48	5.97
10.50	**T19**	19.11	6.25	**M16**	15.69	4.84	**B4**	17.24	4.73
11.00	**T16**	17.27	5.26	**M7**	19.74	5.43	**B24**	18.95	5.36
11.50	**T6**	18.01	4.66	**M12**	18.44	5.17	**B21**	18.81	5.11
12.00	**T3**	18.68	6.51	**M8**	17.17	4.87	**B28**	19.04	5.34
12.50	**T4**	17.48	5.29	**M9**	16.59	4.63	**B25**	18.23	5.01
13.00	**T25**	15.61	5.51	**M6**	17.53	5.70	**B31**	18.92	5.59
13.50	**T22**	16.65	5.57	**M28**	16.61	4.77	**B3**	19.13	5.31
14.00	**T1**	19.54	6.73	**M2**	19.73	6.21	**B2**	19.79	5.49
14.50	**T2**	18.69	6.15	**M5**	17.23	4.88	**B5**	17.98	5.28
15.00	**T7**	18.29	5.67	**M4**	19.70	5.38	**B29**	19.43	5.03
24.00	**T28**	17.99	5.45	**M3**	16.56	4.84	**B30**	19.56	5.35

Table A6: Table of Samples Condition after Being Stored for 5 days in Open Air Room Condition

Samples from Sun Drying Experiment Stored in Open Air Room Condition										
Day	A		B		C		B2		C2	
	Weight %	MC %	Weight %	MC %	Weight %	MC %	Weight %	MC %	Weight %	MC %
1	83.31	53.31	56.66	26.66	33.60	3.60	82.13	52.13	33.08	3.08
5	75.42	45.42	45.58	15.58	36.80	6.80	64.22	34.22	31.83	1.83

Table A7: Sample 3 day sun drying (1st day)

1st day - 3/8/2011 (Cloudy Day)

					Weight (kg)			Weight (%)		
Time	Temp (°C)	Sun Ray (W/m^2)	Atm Mst. (%RH)	Wind Speed (m/s)	A	B	C	A	B	C
10.30	29.5	465	92	0.2	2.360	1.995	2.095	100.0	100.0	100.0
11.30	33.3	555	73.6	1.3	2.338	1.944	1.907	99.1	97.4	91.0
12.30	34.7	630	65.7	0.7	2.307	1.865	1.660	97.8	93.5	79.2
1.30	33.9	250	62.8	0.7	2.280	1.793	1.429	96.6	89.9	68.2
2.30	33.5	136	64.1	0.3	2.261	1.744	1.304	95.8	87.4	62.2
3.30	Raining (Stored in room)									

Table A8: Sample 3 day sun drying (2nd day)

2nd day - 4/8/2011 (Cloudy Day)										
					Weight (kg)			Weight (%)		
Time	Temp (°C)	Sun Ray (W/m^2)	Atm Mst. (%RH)	Wind Speed (m/s)	A	B	C	A	B	C
10.30	30.1	455	84.9	0.2	2.206	1.711	1.280	93.5	85.8	61.1
11.30	29.4	311	77.6	1.3	2.181	1.651	1.117	92.4	82.8	53.3
12.30	30.5	186	74.4	0.3	2.167	1.619	1.036	91.8	81.2	49.5
1.30	33	720	62.8	1.3	2.149	1.575	0.908	91.1	78.9	43.3
2.30	31.5	390	64.1	0.3	2.130	1.531	0.822	90.3	76.7	39.2
3.30	31.4	234	65.5	0.2	2.115	1.495	0.785	89.6	74.9	37.5
4.30	31.1	144	70.1	0.2	2.104	1.471	0.778	89.2	73.7	37.1
5.30	32.7	322	66.4	0.2	2.100	1.442	0.776	89.0	72.3	37.0

Table A9: Sample 3 day sun drying (3rd day)

3rd day - 5/8/2011 (Sunny Day)										
					Weight (kg)			Weight (%)		
Time	Temp (°C)	Sun Ray (W/m^2)	Atm Mst. (%RH)	Wind Speed (m/s)	A	B	C	A	B	C
9.30	28.2	421	91.7	0.2	2.065	1.428	0.803	87.5	71.6	38.3
12.30	31.5	730	69.7	0.3	NT	NT	NT	NT	NT	NT
3.30	34.6	616	60.2	1.1	NT	NT	NT	NT	NT	NT
5.30	33.0	398	63.4	0.3	1.966	1.187	0.704	83.3	59.5	33.6

*NT = not taken

Table A10: Summary of 3 day sun drying

		Moisture lost (%)			Moisture change (-%/hour)		
Day	Time	A	B	C	A	B	C
1	10.30	0.0	0.0	0.0	0	0	0
	11.30	0.9	2.6	9.0	0.9	2.6	9
	12.30	2.2	6.5	20.8	1.3	3.9	11.8
	1.30	3.4	10.1	31.8	1.2	3.6	11
	2.30	4.2	12.6	37.8	0.8	2.5	6
	Stored (for 20 hours)						
2	10.30	6.5	14.2	38.9	0.115	0.08	0.055
	11.30	7.6	17.2	46.7	1.1	3	7.8
	12.30	8.2	18.8	50.5	0.6	1.6	3.8
	1.30	8.9	21.1	56.7	0.7	2.3	6.2
	2.30	9.7	23.3	60.8	0.8	2.2	4.1
	3.30	10.4	25.1	62.5	0.7	1.8	1.7
	4.30	10.8	26.3	62.9	0.4	1.2	0.4
	5.30	11.0	27.7	63.0	0.2	1.4	0.1
	Stored (for 16 hour)						
3	9.30	12.5	28.4	61.7	0.094	0.043	-0.081
	5.30	16.7	40.5	66.4	0.525	1.513	0.5875

Table A11: One day sun drying in Sunny Weather

5/8/2011 (Sunny Day)								
					Weight (kg)		Weight (%)	
Time	Temp (°C)	Sun Ray (W/m^2)	Atm. Mois. (%RH)	Wind Speed (m/s)	B2	C2	B2	C2
9.30	28.2	421	91.7	0.2	3.049	3.594	100.00	100.00
12.30	31.5	730	69.7	0.3	2.717	2.422	89.100	66.4
3.30	34.6	616	60.2	1.1	2.590	1.710	85.210	45.58
5.30	33.0	398	63.4	0.3	2.504	1.189	82.125	33.08

Table A12: Fresh (wet) samples storing experiment

Storing (fresh wet sample)						
)ay	Open Air			Close Air		
	weight (kg)	Weight (%)	Weight loss/day (%)	weight (kg)	Weight (%)	Weight loss/ day (%)
	2.142	100.00	0	2.047	100.00	0
	2.003	93.51	6.49	2.045	99.90	0.1
	1.822	85.06	8.45	2.042	99.76	0.14
	1.379	64.38	5.17	2.033	99.32	0.1

Table A13: Data on samples from sun drying experiments storing

Samples Stored in Open Air Room Condition					
	A	B	C	B2	C2

Day	weight (kg)	weight %	weight (kg)	weight %	weight (kg)	weight %	weight (kg)	weight %	weight (kg)	weight %
1	1.97	83.31	1.19	56.66	0.70	33.60	2.50	82.13	1.19	33.08
5	1.78	75.42	0.96	45.58	0.77	36.80	1.96	64.22	1.14	31.83

Table A14: Data on Dried Samples being stored until 134 days

Storing (dried sample) - close air, 134 days						
Sample	Fresh wt. (g)	Dried wt. (g)	Dried wt (%)	Stored wt (g)	Stored wt (%)	Moisture gain (%)
M1	26.05	9.29	35.66	9.70	37.24	**1.57**
M2	30.46	9.84	32.30	10.29	33.78	**1.48**
M3	26.29	8.94	34.01	9.16	34.84	**0.84**
M4	34.66	11.06	31.91	11.52	33.24	**1.33**
M5	24.33	8.00	32.88	8.26	33.95	**1.07**
M6	38.47	12.67	32.93	13.07	33.97	**1.04**
M7	30.08	9.64	32.05	10.05	33.41	**1.36**
M8	28.87	9.35	32.39	9.77	33.84	**1.45**
M9	31.91	10.83	33.94	11.28	35.35	**1.41**
M10	35.15	11.90	33.85	12.42	35.33	**1.48**
M11	35.87	11.02	30.72	12.57	35.04	**4.32**
M12	27.61	9.42	34.12	9.88	35.78	**1.67**
M13	29.99	10.13	33.78	10.60	35.35	**1.57**
M14	32.74	9.74	29.75	10.22	31.22	**1.47**
M15	36.37	11.85	32.58	12.41	34.12	**1.54**
M16	29.26	9.66	33.01	10.14	34.65	**1.64**
M17	35.98	12.26	34.07	12.89	35.83	**1.75**
M18	29.24	9.52	32.56	9.98	34.13	**1.57**
M19	30.11	9.37	31.12	9.84	32.68	**1.56**
M20	36.88	12.64	34.27	13.29	36.04	**1.76**
M21	41.29	12.60	30.52	13.21	31.99	**1.48**
M22	34.04	11.43	33.58	12.01	35.28	**1.70**
M23	29.05	8.92	30.71	9.36	32.22	**1.51**
M24	28.09	8.43	30.01	8.87	31.58	**1.57**
M25	36.41	12.30	33.78	12.91	35.46	**1.68**
M26	34.02	11.53	33.89	12.09	35.54	**1.65**
M27	35.18	12.68	36.04	13.30	37.81	**1.76**
M28	35.89	11.39	31.74	11.95	33.30	**1.56**
AVERAGE			**32.79**		**34.39**	**1.60**

Table A15: Continuous Drying With Halogen Moisture Analyzer Results

Time (min)	Weight (%)	Weight (g)	Moisture Removed (%)
0	100	18.53	0
10	92.27	17.1	7.73
20	83.12	15.4	16.88
30	74.9	13.88	25.1
40	67.66	12.54	32.34
50	61.38	11.37	38.62
60	55.92	10.36	44.08
70	51.28	9.5	48.72
80	47.47	8.8	52.53
90	44.49	8.24	55.51
100	42.28	7.83	57.72
110	40.68	7.54	59.32
120	39.53	7.32	60.47
130	38.71	7.17	61.29
140	38.16	7.07	61.84
150	37.85	7.01	62.15
160	37.68	6.98	62.32
170	37.61	6.97	62.39
180	37.56	6.96	62.44
190	37.53	6.95	62.47
200	37.5	6.95	62.5
210	37.48	6.95	62.52
220	37.47	6.94	62.53
230	37.45	6.94	62.55
240	37.44	6.94	62.56
250	37.42	6.93	62.58
260	37.42	6.93	62.58
270	37.41	6.93	62.59
280	37.4	6.93	62.6
290	37.39	6.93	62.61
300	37.38	6.93	62.62

Table A16: Tools Specifications

Tools	Specification
Carbolite 450 Oven	➢ Temperature Range up to 300°C ➢ Exterior Dimensions (WxDxH) 47 x 33.5 x 36 inch ➢ Interior Dimensions (WxDxH) 24 x 24 x 24 inch ➢ Voltage: 208 - 240 V
HR73 Halogen Moisture Analyser	**Dryer** ➢ Heating element: Halogen ring-shaped radiator ➢ Temperature range: 50–200 °C ➢ Temperature step: 5 °C (HR73: 1 °C) ➢ Temperature adjustment: with temperature adjustment set HA-TC or HA-TCC **Balance** ➢ Minimum sample weight: 0.1 g ➢ Maximum sample weight: 1) 51 g (HR73: 71 g) ➢ Weight adjustment : with external weight, 50 g ± 0.1 mg ➢ Units: g, % moisture content, % dry content, ATRO moisture content, ➢ ATRO dry content ➢ Stability detector: with symbol in display ➢ Readability of the balance: 1 mg ➢ Readability of the result: 0.01% ➢ Repeatability with 1 g sample2): ±0.2% ➢ Repeatability with 10 g sample2): ±0.02% **Data** ➢ Time, date system clock, fail safe ➢ Drying time: manual, 30 seconds to 480 minutes ➢ Operational settings: read-only memory, fail safe ➢ Switch-off criteria: 5 levels, manual, timed, test, free ➢ Method memories (fail safe): 20 ➢ Drying programs: standard, fast, gentle, steps (3) ➢ Sample identification : alphanumeric, 20 characters ➢ Company name: alphanumeric, 20 characters ➢ Reset protection: by locking the keypad ➢ Weighing-in aid (target weight): 0.1–51 g (HR73: 0.1–71 g) in 0.1 g steps ➢ Limit values weighing-in aid: 1–25% (1% steps)
Sun Meter	➢ DLM531 Features: • For Simple One Hand Operation • Accurate Visible Compensation Filter f1 is Used. • CIE (λ):f1<2%,<3%,<5%,<8%,v(λ)Match (CIE photopic f'1 No Specified) • Cosine Response:f2<2% • Range : 20 Lux,200 lux, 2000 lux, 20,000 Lux ; 20fc, 200fc, 2000fc, 20,000fc

	• Analog Output Standard (output impedance 500 ohm) • Valox Housing to Withstand Accidental Drops • Digital and Analog Output Function • Highly accurate f1 Compensation and Diffuser f2<2% • Peak Data Hold Function • Backlit LCD Display • High Accuracy : ±3%rdg+10dgts 3 1/2 digit LCD display with a maximum reading of 1999 • Automatic Zero ➢ DLM 531 light meter Specifications: • Photometric Formulas: • 1 footcandles = 10.764 Lux (lumens/meter2) • 1 Lux (lumens/meter2) = 0.0929 footcandles • Ranges: 20lux, 200lux, 2,000lux, 20,000lux ; 20fc, 200fc, 2000fc, 20,000fc • Resolution: 0.01lux. ; 0.01 fc • Spectral response: CIE photopic • Acceptance angle: f2<2% cosine corrected (150°) • Total accuracy: for CIE standard illuminate A (2856K);(±3%rdg+10dgts) • Sampling rate: 3 times/per second • General • Power Requirement: 4 pieces 1.5V (AAA size) batteries • Dimensions: 6.7"x1.7"x1.6" (170x44x40mm) • Weight: 7.7 oz(220g) • Accessories: Test leads, soft carrying case, and owners manual.
Digital Anemometer	➢ Model name: General DAF2005MDL, Digital Vane Anemometer with Real Time Data Logging ➢ High Capacity 16,000 Data Logger no. ➢ Real Time Data Logger - records Year, Month, Date, Hour, Minute and Seconds ➢ Measures Air Velocity, Airflow, Temperature and Type "K" & "J" Temperature ➢ Heavy Duty Metal Vane ➢ Jumbo LCD Display ➢ Min/Max ➢ Data Hold ➢ S232 computer interface ➢ .5 to 30.0 m/s CMM, CFM ➢ Power Source - DC 1.5V UM3 & 4 "AA" Batteries ➢ Size: 203 x 76 x 38 mm.
Digital Psychrometer (Extect Heavy Duty Moisure Meter)	➢ Features: • Super large 1.4" (36mm) LCD display • Displays wood moisture content from 9-30% with a • 0.1% resolution • Memory contains 9 material groups including • calibrations for approximately 150 species of wood • Built-in self calibration with manual temperature • compensation adjustment • Record/Recall MIN/MAX readings

	• Data Hold plus Auto shut off • Built-in RS-232 serial interface for connection to a PC • Complete with 2 pin moisture probe, 40" cable, • 10 spare pins, protective holster, and 9V battery ➢ Interface Options: • Optional Windows® Data Acquisition Software and • serial cable enable user to display and capture • readings • on a PC, and set time intervals and alarms • Optional battery operated Datalogger module stores • over 8000 readings for later transfer to a PC ➢ Applications: • Wood products, Furniture making/repair, • wood floor manufacturing & installation, wood drying, • building inspection, pest control, lumber inspection, • fire damage, and water damage ➢ Specifications: • Range / accuracy(%rdg+digits): 9% to 30% / ±(4%+5d @9-24%) • Resolution: 0.1% • Sampling time: 0.8 second • Manual Temperature Compensation: 32 to 122°F (0 to 50°C) • Dimensions/Weight Meter: 7x2.9x1.3" (180x72x33mm) / 12.3oz (350g), Probe: 0.9" (23mm)D 6.5" (165mm)L

Procedures A1: OPF Feedstock Continuous drying experiment using CARBOLITE 450 oven procedures

1. Some of the prepared samples are then being experimented with the continuous drying experiment using CARBOLITE 450 oven to estimate the moisture content. In this experiment 9 number of samples are being used (3 from tip, 3 from middle and 3 from bottom)
2. The oven are being warmed empty first with the temperature of 105 °C.
3. After about 2 minutes, all of the samples are then being put inside the oven and the time is taken and set to minute 0.
4. For every 30 minutes interval, all of the samples are being taken out of the oven, and the mass of every sample were measured and recorded. All of the samples were putted back into the oven right after there were measured. (The process should take no more than 3 minutes)
5. After measuring the samples continuously for 15 hour (with every 30 minutes interval), the samples are then being put inside the oven for 9 hour straight before taking the final weight measurement.
6. The total time taken was about 24 hour and the drying/heating process ends (refers table 2.0 in appendix for results data).

Procedures A2: OPF Feedstock Non continuous drying experiment using CARBOLITE 450 oven procedures

1. A total of 93 OPF samples were taken from the prepared samples (31 from tip, 31 from middle, 31 from bottom). The samples were experimented with the non continuous drying method using CARBOLITE 450 oven
2. The oven are being warmed empty first with the temperature of 105 °C.
3. After about 2 minutes, all of the samples are then being put inside the oven and the time is taken and set to minute 0.
4. For every 30 minutes interval, 3 of the samples were taken out from the oven (one from tip, one from middle and one from bottom) and their weight were being measured. The measured samples are not returned back to the oven; rather, they are kept outside for the other use.

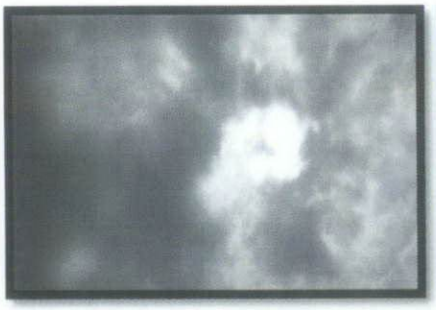
5. The last tree samples (one from the tip, one from the middle, one from the bottom) are kept in the oven for twenty four hours total. After twenty four hours, the samples are taken out and the weights are measured (refers table 3.0 in appendix for results data)

Procedures A3: OPF Granule Continuous drying experiment using HR73 Halogen Moisture Analyzer

1. 9 samples are prepared (3 from bottom, 3 from middle and 3 from tip) with the weight of between 1.41g to 3.65g and average size of 25 mm in length and were turned into powder/granule size by using granular machine.
2. The total initial weight of all samples measured by the HR73 Halogen Moisture Analyzer is 18.53g.
3. The drying temperature was set to 105 °C
4. Starting from minutes 0, for every 10 minutes interval, the weight of the sample are being recorded.
5. The total drying time taken was 300 min. (refers Table 4.8 in appendix for the results data).

Procedures A4: 3 Days Sun Drying (Cloudy Weather)

1. 3 samples each one consisting of a whole different fresh OPF were prepared into 3 different categories which are A, B and C (like described in section 4.2.1).
2. The initial weights of each sample were measured.
3. Each sample were placed and spread on sun drying stand starting at 10:30 a.m.
4. For each interval of an hour, the weight of each samples and the weather condition (temp, sun ray, atmosphere humidity, and wind speed) were measured.
5. During the first day, 4 hours of sun drying were conducted until the samples were stored inside a room after 2:30 p.m because it was starting to rain.
6. Sun drying process of the samples continued for 7 more hours on the 2nd day starting at 10:30 a.m. until 5.30 p.m. The samples being stored in room after 5:30 p.m.
7. The sun drying process continued for 8 more hours on the 3rd day, because of the sunny weather, the process could be start earlier which is at 9:30 a.m. For the 3rd day, the samples were not disturbed/ measured until the final reading was taken at 5:30 p.m.
8. The experiment data could be refers to Table 4.0, Table 4.1,Table 4.2 and Table 4.3 in the Appendices.

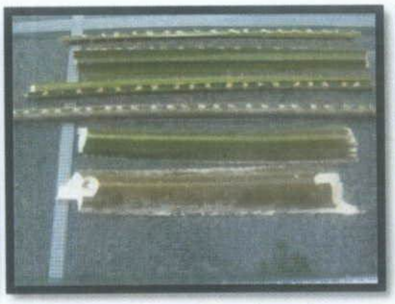


a) Cloudy sky during the 1st day

b) Cloudy sky during the 2nd day

c) samples being spread on drying stand 30 ° facing the sun

d) sample B placed on drying rack



e) sample A placed on drying rack

f) sample C placed on drying rack

Figure A1: Three days Sun Drying Experiment

Procedures A5: 1 Day Sun Drying (Hot and Sunny Weather)

1. 2 samples each one consisting of a whole different fresh OPF were prepared into two categories which are B2 and C2 (like described in section 4.2.1)
2. The initial weights of each sample were measured.
3. Each sample were placed and spread on sun drying stand starting at 9:30 a.m.
4. The weight of each samples and the weather condition (temp, sun ray, atmosphere humidity, and wind speed) were measured and recorded after 3 hour, 6 hour and 8 hour occasionally. Refer to Table 4.4 in appendix for the experiment data

Figure A2: Sunny Day Sun Drying Experiment

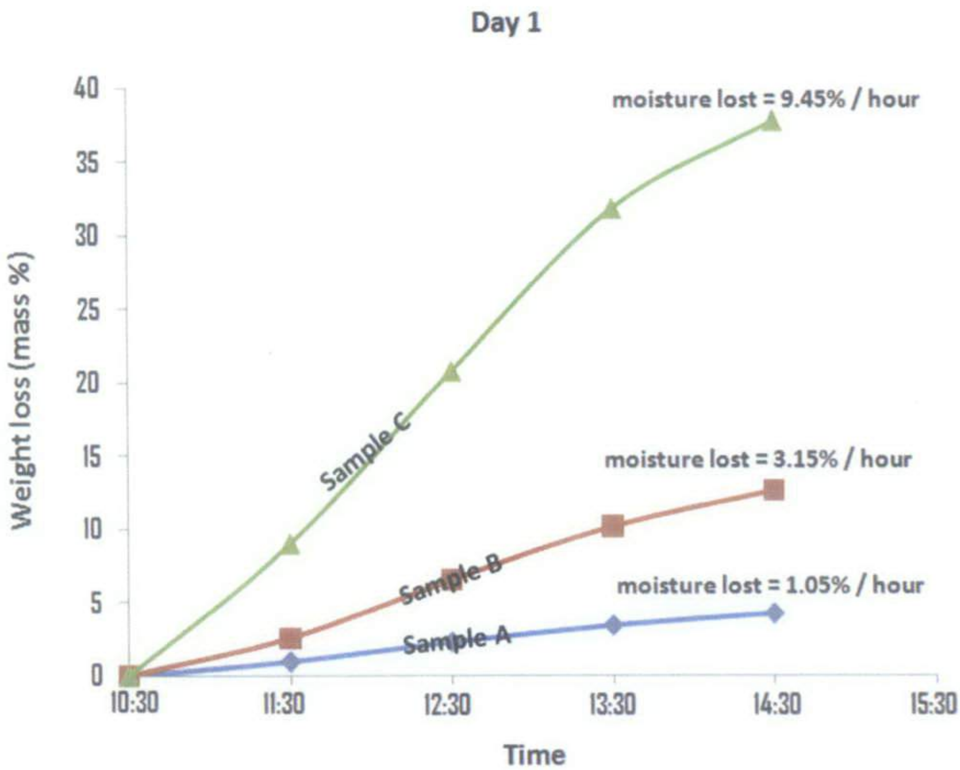


Figure A3: Day 1 of 3 Days Sun Drying (Cloudy Weather)

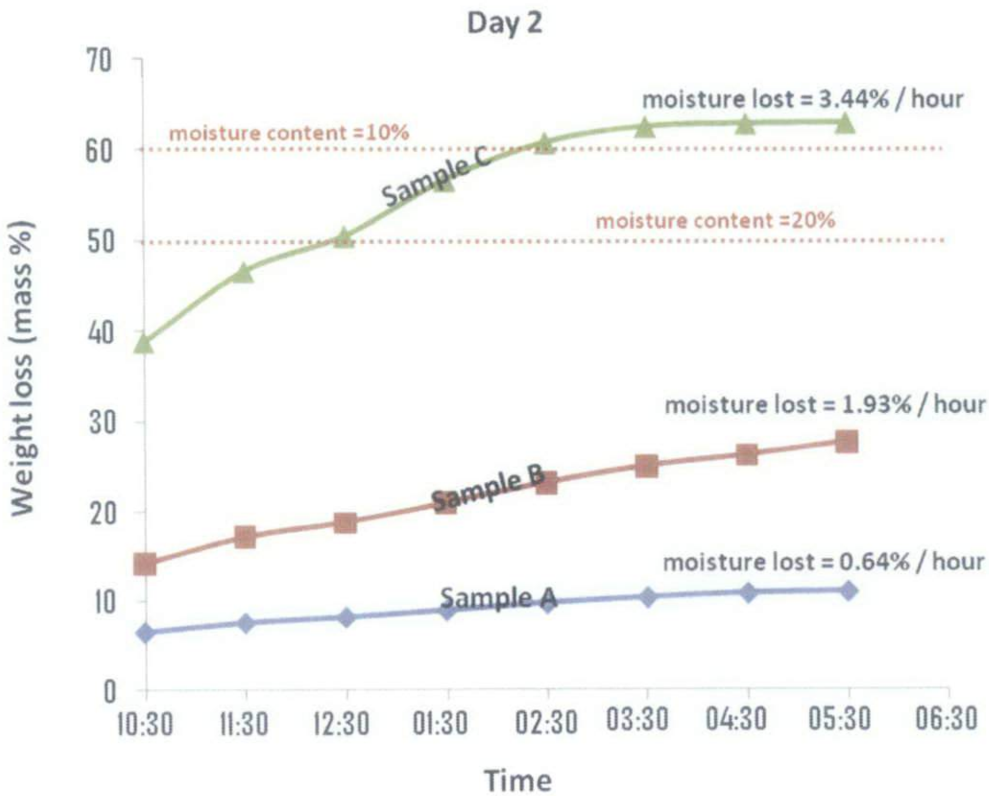


Figure A4: Day 2 of 3 Days Sun Drying (Cloudy Weather)

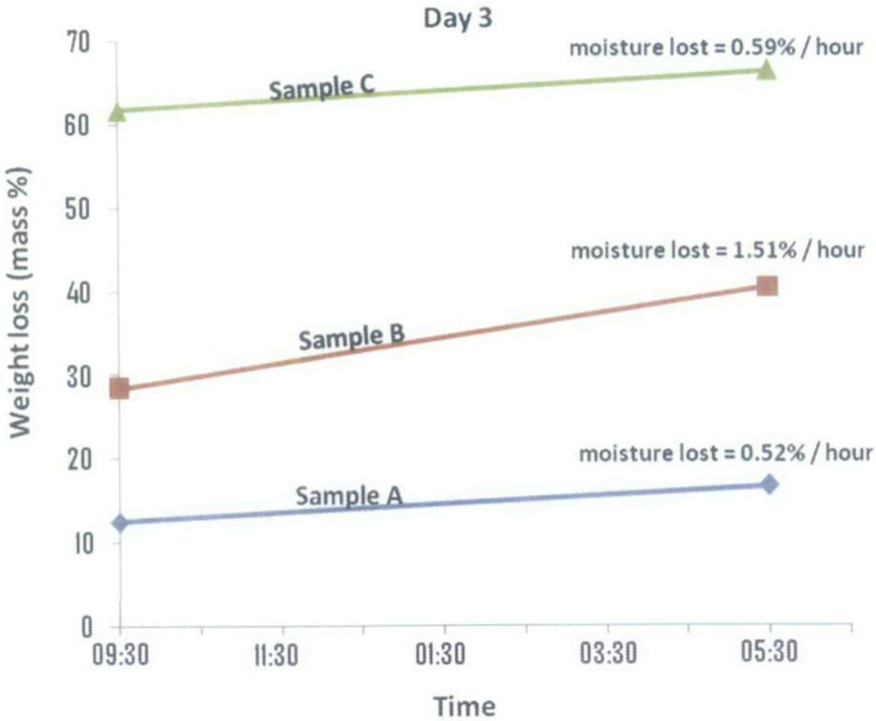


Figure A5: Day 3 of 3 Days Sun Drying (Cloudy Weather)

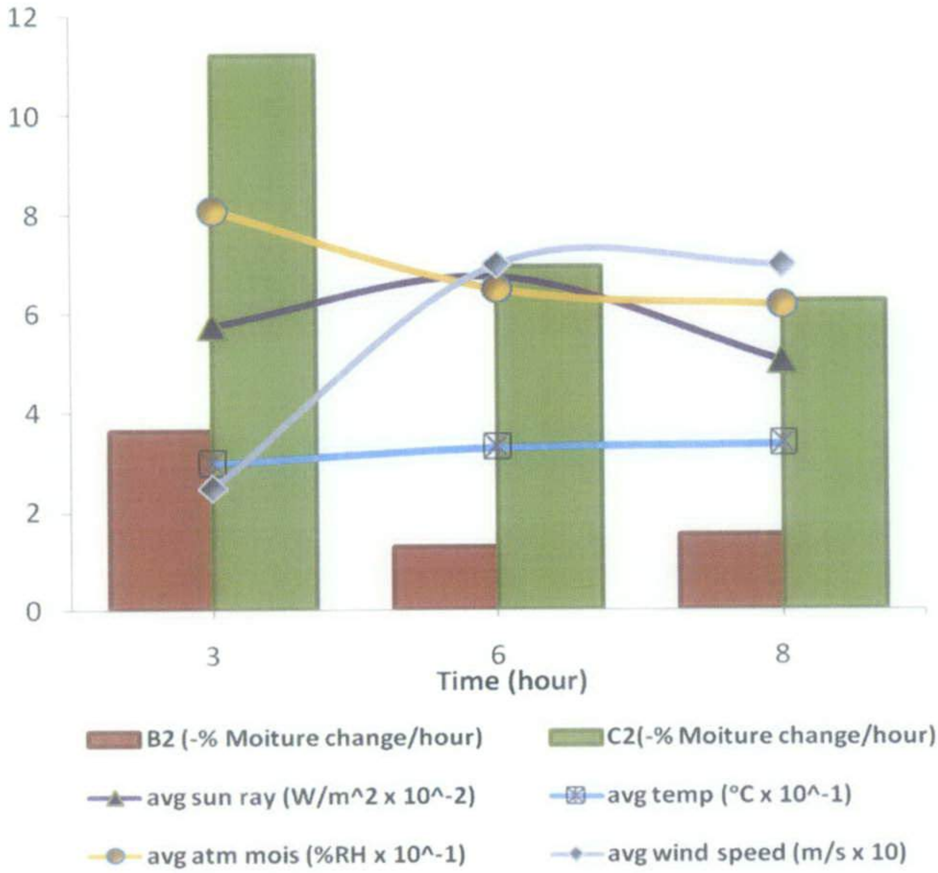


Figure A6: Weather factor graft on a Sunny Day Sun Drying

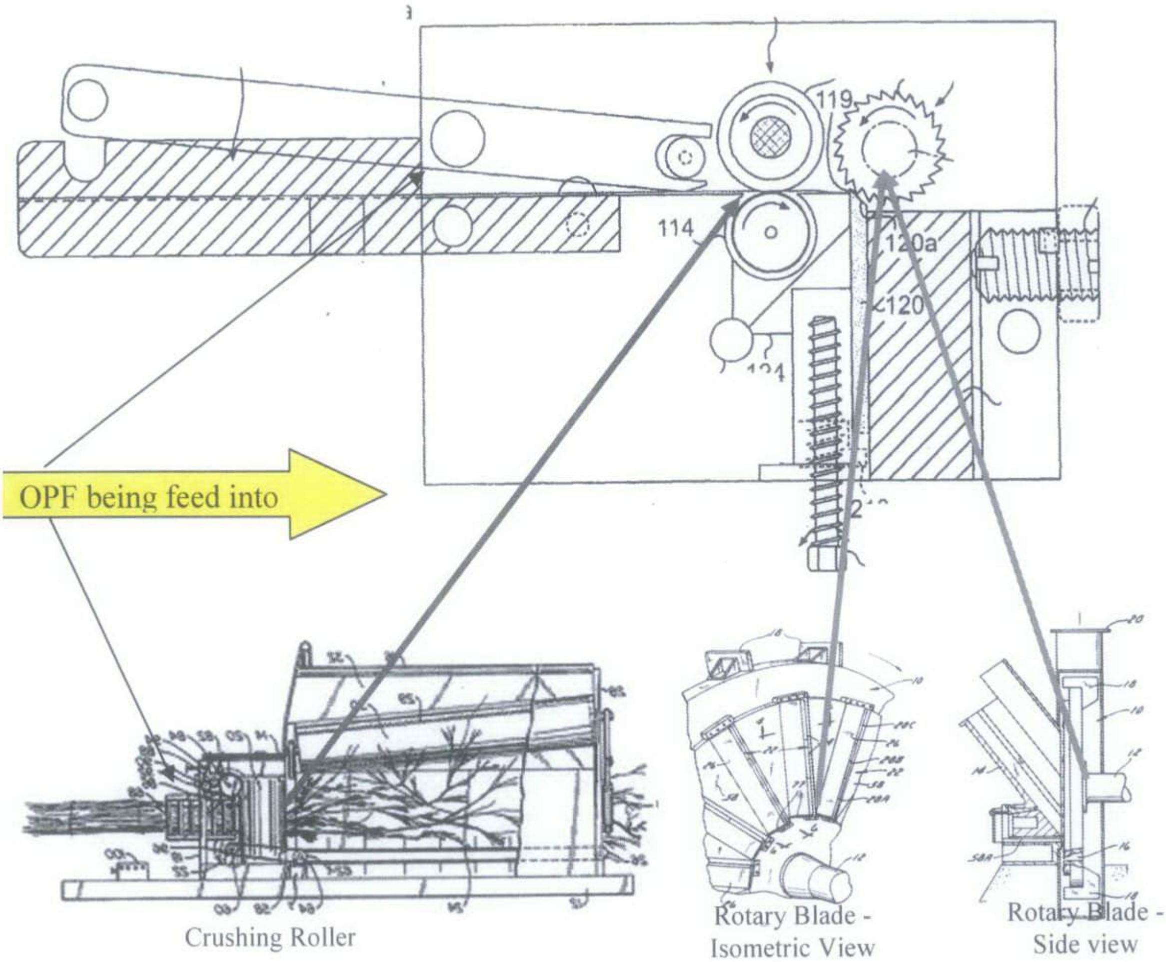


Figure A7: Basic Wood Chipper Mechanisms

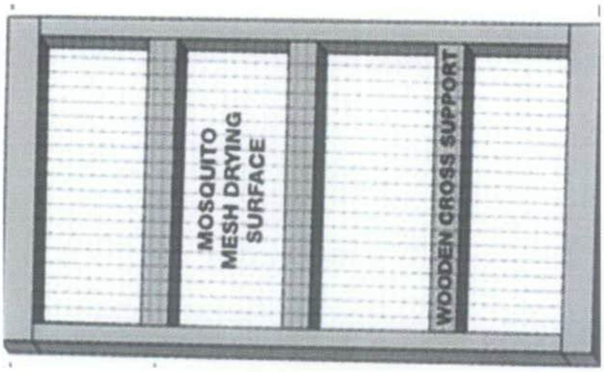


Figure A8: Sun Drying Rack, C: AVA 2010

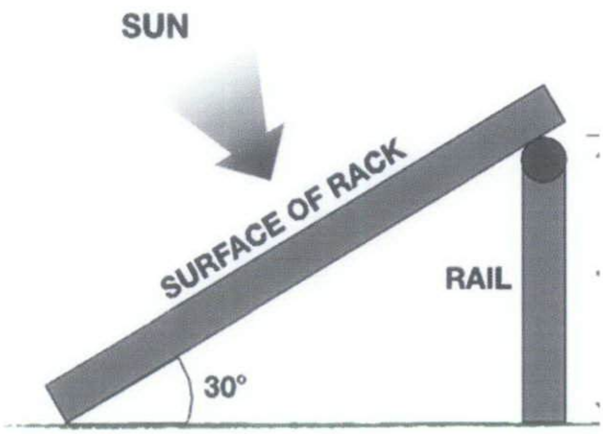


Figure A9: Inclined Sun Drying Stand, C: AVA 2010

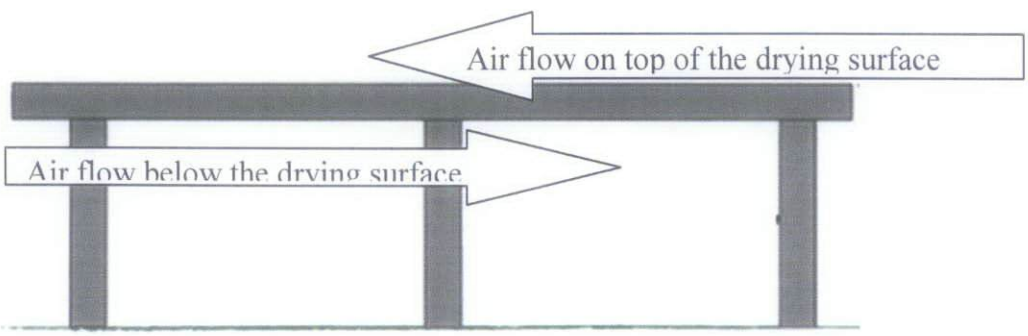


Figure A10: Basic Sun Drying Stand, C: AVA 2010